United States Department of Agriculture

Forest Service

Intermountain Forest and Range Experiment Station Ogden, UT 84401

General Technical Report INT-173

November 1984

Research Natural Areas: Baseline Monitoring and Management

Proceedings of a Symposium in Missoula, Montana, March 21, 1984

Each contributor submitted camera copy and is responsible for the accuracy and style of his or her paper. Statements of contributors from outside the U.S. Department of Agriculture may not necessarily reflect the policy of the Department.

PESTICIDE PRECAUTIONARY STATEMENT

This publication reports research involving pesticides. It does not contain recommendations for their use, nor does it imply that the uses discussed here have been registered. All uses of pesticides must be registered by appropriate State and/or Federal agencies before they can be recommended.

CAUTION: Pesticides can be injurious to humans, domestic animals, desirable plants, and fish or other wildlife—if they are not handled or applied properly. Use all pesticides selectively and carefully. Follow recommended practices for the disposal of surplus pesticides and pesticide containers.

PROTECT

Use Pesticides Safely

FOLLOW THE LABEL

U.S. DEPARTMENT OF AGRICULTURE

The use of trade, firm, or corporation names in this publication is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by the U.S. Department of Agriculture of any product or service to the exclusion of others that may be suitable.

Research Natural Areas: Baseline Monitoring and Management

Proceedings of a Symposium in Missoula, Montana, March 21, 1984

Coordinators:

Janet L. Johnson, Northern Region

Jerry F. Franklin, Pacific Northwest Forest and Range Experiment Station

Richard G. Krebill, Intermountain Forest and Range Experiment Station

Sponsored by the U.S. Department of Agriculture, Forest Service, Northern Region and Intermountain Forest and Range Experiment Station; the University of Montana; Northwest Scientific Association; and Montana Academy of Sciences.

ACKNOWLEDGMENTS

The coordinators express appreciation to our sponsors for their support, to the Northern Region Research Natural Area Committee and The Nature Conservancy for their encouragement, to Dorothy Dryden for assuring completion of every task we undertook, to Louise Kingsbury for leading production of these proceedings, and especially to Steve Arno and Chuck Wellner who were catalysts to the idea and organization of the symposium.

We also express our special thanks to all our excellent speakers, to Jim Habeck, who helped as moderator, to the many displayers of top-notch posters, and to the 60 to 80 participants who joined with us throughout the symposium and shared their thoughts on how to improve the usefulness of research natural areas.

DEDICATION

Dedicated to Charles A. Wellner, recipient of The Nature Conservancy's coveted "Oak Leaf Award."

This award was presented by Dr. Steven C. Buttrick at this symposium to Chuck for his especially dedicated service to natural area ideals. Throughout his Forest Service career, Chuck was a major proponent for the establishment and scientific use of research natural areas. In 1974, after retirement, Chuck helped organize the Idaho Natural Areas Coordinating Committee, a select group committed to the preservation of undisturbed tracts of land and water for research and education. Chuck has been remarkably successful in proposing and helping to establish research natural areas in lands of the National Forest System, the State of Idaho, and the Bureau of Land Management. Chuck's interest spans the range of biological and physiogeographical attributes. His enthusiasm has been an inspiration to us all and has done much to foster the preservation of both representative and unique natural area sites.

CONTENTS

KEYNOTE COMMENTS: PROPHYLAXES FOR OUR RESEARCH NATURAL AREA SYSTEM

Jerry F. Franklin, presented by Robert D. Pfister

ABSTRACT: Three problem areas that could threaten the integrity of the research natural area system are discussed: (1) lack of scientific use; (2) inadequate documentation of the research methods and marking of installations in the field; and (3) inadequate management (stewardship) programs. Suggestions are made to remedy these conditions.

INTRODUCTION

Things are going well in our natural area programs. In most States, we either have or are developing comprehensive plans for natural area systems--plans that coordinate activities of many agencies and organizations. The Nature Conservancy's heritage programs are abetting the work with identification of elements or cells of interest and their locations. Natural areas are being incorporated into Forest Service land-use planning; many new research natural areas will presumably emerge. The Bureau of Land Management has greatly simplified its establishment procedures, releasing a tide of new research natural areas. States and The Nature Conservancy are identifying and protecting endangered habitats as a part of critical-area programs, one of which has just been successfully completed in California.

Some of the problems are obvious. When the National Forest plans are finalized, will all of the identified areas actually get established? Dollars are short for research and monitoring. In some States, including Oregon, State programs are high-centered, unable to get sufficient funds or agency support for establishment of natural areas.

Nonetheless, we could congratulate ourselves on our advances. Progress has been made in identification and establishment of areas, in general recognition of the value of research natural areas, and in acceptance of these programs by managers.

A keynoter--even in absentia--might be expected to deliver a positive statement. I choose not to make such a statement, however, for the dark clouds ahead could create major problems for our research natural area system unless appropriate measures are taken.

Jerry F. Franklin is Chief Plant Ecologist at the Pacific Northwest Forest and Range Experiment Station, USDA Forest Service, Corvallis, Oreg. Robert D. Pfister is at the Forestry School, University of Montana, Missoula.

Some potential dangers to our research natural area system are: (1) the minimal use by scientists of the existing research natural areas; (2) inadequate documentation of what has been done, including work intended to provide a long-term data base; and (3) insufficient attention to stewardship of reserves. My intention is to characterize these dangers and to propose some remedial actions. Without such prophylactic measures, I question whether our natural area system will persist.

USE IT OR LOSE IT

Establishing a research natural area or reserve does not insure its existence in perpetuity--regulation, law, or ownership, notwithstanding. Federal research natural areas are going to be reviewed periodically by the responsible agency. Land-use planning on the National Forests may mean, for example, a major round of establishing research natural areas after plans are adapted. But it also insures that this designation is going to be reviewed at 10-year intervals--at each planning cycle.

Many questions will be posed at each review. The most critical question may be, "Has anybody used this natural area?" However much we may argue (and believe) that reserves have value even without any use, managers and the public are going to find such arguments unconvincing. Managers already complain constantly of the real or imagined lack of scientific use of existing research natural areas. Each cycle of land-use planning--of reassessment--will be a moment of truth in which concrete evidence of use by the scientific community will be essential. Have we put our energies and our dollars where our mouths are?

The importance of using natural areas is not confined to Forest Service or Bureau of Land Management research natural areas. It will almost certainly come to apply to all lands exempted from normal social uses for scientific purposes. The Nature Conservancy and other private reserves are commonly granted tax exemptions based on scientific and other benefits to the public. We can be sure that this contribution will be periodically examined. Even areas designated as Wilderness or as National Parks are going to be periodically reassessed. Wilderness, in particular, has been justified partially on scientific grounds, but agency attitudes and regulations have relegated research to a minor activity; I expect to see an accounting for the paucity of research in Wilderness locations in the future.

Many factors contribute to low scientific use of existing research natural areas. Scientists often do not know of the existence and variety of ecosystems found in natural areas. Funds and time are short, discouraging use of a more remote site even though it is protected. I have heard scientists offer various rationales as to why they could not use an established research natural area or experimental forest; some of these scientists have been very vocal in insisting agencies establish them.

Natural scientists are responsible for seeing that appropriate use is made of natural areas in their own studies and those of others. We need to begin pointing out natural areas to fellow scientists, making the extra commitments of dollars or time necessary to use natural areas in our own work, and criticizing colleagues who fail to use appropriate areas for their research. Managing agencies, as well as the scientific community, must be kept informed of studies.

Funding agencies bear a special responsibility to see that scientists use appropriate research natural areas and other scientific reserves. This burden lies with the panels that provide peer reviews and recommendations, as well as program managers in organizations such as the National Science Foundation. Strong encouragement--even coercion of reluctant peers--may be justified.

The scientific community must begin to put up or shut up; if we do not use our scientific reserves we will almost certainly lose them. We need to take this responsibility seriously.

LEAVING TRACKS

Documentation is the key to any research or monitoring program that purports to be of long-term value. What were the objectives of the research? Where was the sampling conducted--the geographic location within the research natural area? Can the plots be relocated? What methods, instruments, were used? Where are the original data? Have they been duplicated and archived in a safe place? Have the data been entered in electronic form and subsequently verified?

I contend that--with a few notable exceptions--the scientific community has done an abominable job of plot monumenting and field marking, study documentation, and data archiving. How many times have we attempted to revisit old plots, use old data sets, repeat measurements, and so on--and been totally frustrated because we could not tell what had actually been done? Part of this is a consequence of an unwarranted belief in our individual abilities to recall critical information at some far-off date. Some of our failure is a consequence of laziness. Agencies contribute to documentation failures by regulations that unnecessarily limit field marking. Institutions discourage (directly or through their reward structures) long-term research perspectives. Many circumstances cause failures and few nurture documentation efforts.

We simply must get this area of field marking and documentation under control or little long-term research and monitoring will be worthy of the name--or the dollars invested in it.

Field marking is where the documentation job starts (not counting the initial study plan). Future scientists have to be able to relocate plots, which requires detailed maps or carefully marked aerial photographs, detailed instructions, and, often, route markings on the ground. In the rugged topography and dense vegetation of many forested mountain regions, relocating a plot can be difficult and time consuming. Plot markings themselves need to be permanent and often as conspicuous as possible. When it comes to marking plots, metal or plastic stakes are better than wooden, taller stakes typically better than shorter, and more stakes better than fewer. Yellow metal signs, 5 by 8 inches, tacked on trees and facing outward from plot edges have been very helpful in guiding researchers back to plots in the shrub- and tree-infested Neskowin Crest Research Natural Area on the Oregon coast. Metal tree tags are usually the fastest and surest way of identifying individual trees for remeasurement; simply tallying trees on a plot provides information of much more limited value and none on the behavior of individual specimens. And so forth.

I am sure that some of you take exception to some or all of these suggestions. I do not propose scientific license in the use of reserves, however, or use of conspicuous markings in recreationally sensitive areas. I do argue that we should use techniques that will provide for reliable and efficient remeasurement programs consistent with maintenance of natural processes. None of the field markings proposed above are likely to have a significant effect on natural processes, but objections to them are sometimes voiced, based primarily on esthetic considerations and not on concern for altered ecological processes. I think that such concerns are grossly misplaced, especially when activities that significantly alter natural processes--such as trapping, hunting, or grazing by domestic livestock--are allowed to continue in and around our research natural areas.

Data documentation and archiving are the other critical areas. During the first several decades of Forest Service research, establishing long-term plots was emphasized; excellent records were laboriously duplicated and maintained, methodologies were standarized or described in detail, and so on. Few modern researchers appear to take the time to protect and document their data sets adequately for the long term. They know what they did--so they often waste no time describing methods, variables, and so on.

Forest Service and university researchers at Oregon State University have had extensive experience in developing a forest-science data bank during the last decade. Long-term data sets are emphasized. Our experience suggests that: (1) documentation of methodology is typically weak, especially for long-term studies in which methods change over time; (2) accountability to a third party, such as a biometrician, improves documentation; (3) data sets need to be periodically analyzed--use invariably surfaces problems in documentation; and (4) data sets need to be archived in data depositories that offer uniform standards of data maintenance and make data retrieval possible and efficient. Art McKee will have some further observations on the virtues of careful documentation later in this symposium.

To summarize, scientists are going to have to learn to leave better tracks for future generations of scientists if their work is to have any value as a long-term baseline. Permanent and conspicuous but ecologically neutral field markings are important. Data archiving and documentation need extensive, continuous, and sometimes expensive attention.

ADOPT-A-NATURAL-AREA

Laissez faire management of natural areas is the third danger area. Simply the absence of management plans for most of the Federal research natural areas suggests that we have a serious problem. Such management as occurs is usually based on general agency guidelines (for example, the Forest Service manual), not on a detailed consideration of specific preserve objectives and the various factors affecting achievement of those objectives.

Developing specific objectives for every natural area is important. What are we trying to achieve? A lack of operational objectives often produces disagreements over management. Some individuals interpret the general guidelines as indicating that succession should be allowed to proceed, even when natural processes have been altered. Others interpret guidelines as a mandate for management to maintain a specific community or organism or to try to duplicate natural processes, such as wildfire, with management. Any or all of these approaches are allowable and may be appropriate on a specific research natural area--depending on the objectives of the particular area, however--which is why analysis of objectives is a key part of preparing a management plan. What do you want to achieve and in what part of the natural area?

Forest Service establishment reports are sometimes considered to be functional management plans, but I have yet to see an establishment report that even provides the detailed information base required to prepare a management plan. The Nature Conservancy is far ahead of the Federal agencies; stewardship plans have been developed for the majority of its preserves, and intensive management to achieve specific preservation objectives is characteristic of many of their properties.

We argue that the natural areas are invaluable, yet the management attention they are receiving is not consistent with those purported values. Management plans are a first step and can help clarify our objectives, as well as define management needs. They can also focus the attention of the busy local managers on these unique properties, identify neccessary investments, and serve as a basis for budgetary requests.

Finances are an additional issue that I will not dwell on here. Many of us are aware that research natural area programs, whether for management or research, are typically financial stepchildren. What is done is primarily through the good will of interested managers and researchers, not because of any institutionalized financial commitment to research natural areas. A lot of buck passing occurs in the area of financial responsibilities.

At least one aspect of stewardship is amenable to our efforts as individuals and small groups. Many natural areas have suffered simply because no interested or knowledgeable parties looked in upon them periodically. When people like Will Moir, Fred Hall, Chuck Wellner, and I have visited research natural areas in the course of preparing guidebooks, we frequently discovered that we were the first to visit them since establishment. Various activities occur that detract from natural area values--poaching for firewood, perhaps, or development of a hunter's camp. A timber sale may intrude because of incorrectly located boundaries. Overburdened agency management personnel are often unable to give the research natural areas the specific attention they deserve.

We could insure that our research natural areas do get regular and sympathetic attention if each of them was adopted by an interested individual or group. This program would at least provide for regular visits during which management problems and developments would be noted. Problems might include inappropriate use, and a development might be a storm that resulted in substantial tree mortality. The results of these visits could be documented, providing the managing agency with a continuing record of developments in the natural area and flagging developing problems before they become critical. The documents would also become part of the scientific record of the natural area.

As with management planning, The Nature Conservancy is ahead of the Federal agencies in volunteer involvement with management and use of natural areas. Many Nature Conservancy preserves have management committees composed of interested scientists and laypersons. These committees sometimes develop and implement the management plans, although many State and regional offices of The Nature Conservancy have

professional stewardship positions, and larger preserves have full-time directors and management staffs. Sometimes universities have assumed responsibility for management and protection of The Nature Conservancy reserves.

Stewardship is currently inadequate for most of our Federal research natural areas. Objectives are often poorly defined, detailed management plans are generally lacking, and funding is inadequate for dealing with a scientific resource that is truly invaluable. We must continually work to improve this situation, but we can take direct action now with an "adopt a natural area" program. As individual scientists, research work units, university departments, junior colleges, citizen groups, or whatever, we can insure that specific research natural areas receive regular visits and that a record of management activities and natural events is created and maintained.

CONCLUSIONS

My apologies to you for this Cassandraic keynote. What follows should be considerably more upbeat. The symposium will, I hope, help to stimulate baseline monitoring and research in the outstanding system of natural areas that we are creating through cooperative Federal, State, and private programs. We must never forget that creating the system is only the first step: eternal vigilance is, unfortunately, essential for a permanent system. The research natural area system needs to be actively managed and to be used for carefully documented research and monitoring. For each of us, a professional commitment above and beyond the scope of anyone's current job description is required--the future of our natural area system relies on philanthropy in the best sense of the word.

Section 1. Baseline Monitoring

BOTANICAL BASELINE MONITORING IN RESEARCH NATURAL AREAS IN OREGON AND WASHINGTON

Sarah E. Greene

ABSTRACT: With human impacts on more and more of the landscape, long-term, high-quality monitoring programs in natural ecosystems are increasingly important. Establishment of botanical monitoring systems in research natural areas in Oregon and Washington is providing baseline data used for (1) testing ecological hypotheses, (2) judging the effects of management activities on similar ecosystems, (3) understanding basic ecosystem processes, and (4) providing data on flora and fauna. Botanical monitoring systems need to be established and carefully referenced, with procedures rigidly defined.

INTRODUCTION

Gene Likens, past president of the Ecological Society of America, stated at the 1983 meeting of the American Institute for the Biological Sciences ". . . .that a major priority for ecology today is to establish long-term studies, including high-quality monitoring programs, in a variety of ecological systems throughout the world. Qualitative and quantitative observations over long periods are vital to formulate meaningful, testable hypotheses in ecology" (emphasis mine). Likens' concept of long-term monitoring studies necessitates research sites that are protected from manipulation where activities such as logging, farming, grazing, and industrial development are not allowed. Federal research natural areas (RNA's) provide these kinds of sites. Representing a wide array of terrestrial and aquatic ecosystems, RNA's are established as permanent study sites to be maintained in their natural condition, with baseline monitoring as a major research focus.

Baseline monitoring on RNA's is not a final objective, but rather a means to an end. Monitoring should provide high-quality data about the ecology of a species, ecology of the community in which it lives, and ecology of the system in which the community exists. Monitoring activities may have a current research objective as well as provide data for future analyses. Ultimately this data will allow the researcher to ask more meaningful questions, to test more viable hypotheses, and to better address the problems of understanding ecosystem processes. This, in turn, will help managers deal with the resource in a way that is more compatible with natural ecological processes.

Sarah E. Greene is Research Forester at the Pacific Northwest Forest and Range Experiment Station, USDA Forest Service, Corvallis, Oreg.

The Pacific Northwest (Oregon and Washington) research natural area program has been emphasizing botanical baseline monitoring for a number of years. Permanent sample plots established in 1947 at the Thorton T. Munger RNA in Washington are still being measured. In the last 10 years monitoring has become an increasingly important concept. The purpose of this paper is to discuss botanical monitoring--studies of long-term duration (greater than 5 years)--using examples from RNA's in Oregon and Washington. This includes a fairly broad range of plant-oriented studies--from floral surveys to mortality analyses. Four categories will be discussed: successional plots, floristic surveys, ecological processes, and classification plots.

SUCCESSIONAL PLOTS

Successional plots, in the form of permanent sample plots, are one part of our monitoring program. If monitoring is to be long term, then permanent installations must be established for consistency, statistical validity, and accuracy of data collection. Permanent sample plots may serve many purposes. In the Pacific Northwest RNA program they have been used primarily to look at growth and yield of stands and to monitor mortality. The program uses two major strategies for establishment of permanent sample plots. One type, called reference stands, can be located in selected plant communities, in a particular stage of succession, or in particular type of environment. The other type, circular plots, is used to systematically sample an area.

Reference stands are generally 1 to 2 ha in size. They are surveyed and marked every 50 m around the perimeter and in the center with plastic or aluminum pipe, and every 25 m with either cedar stakes or reinforcing bar (fig. 1). The entire hectare is then divided into a 5 by 5 m grid to facilitate tree tagging and mapping. Within the plot every tree, 5 cm diameter at breast height (d.b.h.) or greater, is tagged, measured for d.b.h., vigor coded, and stem mapped. Generally 20 to 30 trees, representing 20-cm diameter increments, are measured with an optical dendrometer, which provides information on height, volume, and surface area. All standing or down dead wood, greater than 15 cm diameter, is mapped for size and decay class.

Circular plots, 1 000 m^2, differ somewhat from reference stands (fig. 2). They are surveyed in the center and permanently marked both there and on the circumference at the four cardinal points. Four 12.5-m^2 seedling subplots are

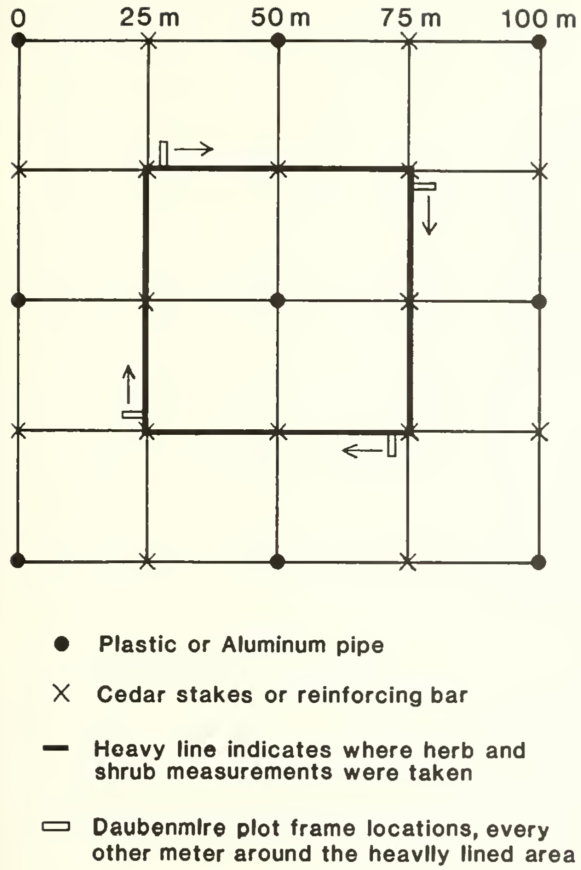


Figure 1.--Reference stand showing permanently marked points and the herb and shrub sampling line.

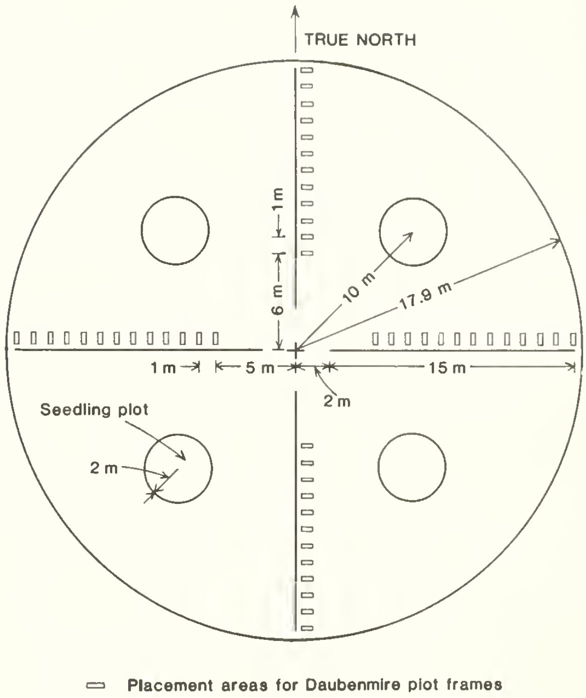


Figure 2.--Circular plot showing center point, seedling plots, and the herb and shrub sampling line.

located 10 m from the plot center. Seedling subplot centers are marked with reinforcing bar. Trees are tagged, measured, and vigor coded. Trees and dead wood are not mapped.

In most cases, herb and shrub vegetation are subsampled in permanent sample plots. The techniques vary. For reference stands a Daubenmire plot frame (20 by 50 cm) is used to measure herb cover. At alternating meters along 200 m of transect (fig. 1) the frame is laid down facing toward the outside of the reference stand. On circular plots the plot frame is laid down at points along four radii emanating from the center in the four cardinal directions (fig. 2). Shrub cover is measured by using the line intercept method along the same transect lines as for the herbs.

Tree mortality checks are made on an annual basis to determine timing and cause of mortality. Every tree in a plot is visited, checked to see if it is dead or alive, and, if dead, measured for d.b.h. and coded for cause of mortality. Tree remeasurements are done approximately every 5 years. Understory vegetation is not ordinarily remeasured unless there is some reason to do so, such as after a wildfire, bug infestation, or mudflow.

All data from permanent sample plots are entered into a micro-computer and stored in the Forest Science Department Data Bank, Oregon State University, Corvallis. Permanent ink maps of the stands have been drawn by hand in the past. Recently a micro-computer program was written that will produce a stem map. A program is currently being developed to map dead wood.

Location of reference stands is a subjective process. Generally an attempt is made to locate the permanent sample plot in a representative stand of a particular forest type or successional stage. Location of circular plots is usually more systematic with plots laid out at regular intervals along transect lines. In some cases a series of transect lines may create a systematic grid of plots. Transect lines may also be oriented to sample across environmental gradients and ecotones.

Because both kinds of plots are permanently marked in the field and are well documented, many other kinds of long-term studies can capitalize on their presence. Mammal population dynamics, insect collections, litter decomposition, biomass sampling, growth and yield of forest stands, nutrient cycling, forest

meteorology, accumulation of heavy metals, and disturbance patterns are some examples of studies that have been done on these plots. The existence of these permanent sample plots also makes data collection by other researchers more cost effective.

As of March 1984 there were 33 ha of reference stands and 250 circular plots, representing 14 different forest types on 15 out of 96 established RNA's in Oregon and Washington.

FLORAL SURVEYS

A floral survey is one of the most basic kinds of botanical monitoring. It can be used both to determine the presence of rare, threatened or endangered species and to get a thorough inventory of plant species, their habitat, and abundance. Until this is done, it is nearly impossible to determine whether changes in individual plant populations or floral compositions are taking place.

Floral surveys can be very time consuming and can differ widely in their usefulness. Fourteen floral surveys have been conducted on RNA's in the Pacific Northwest. Six of these surveys have been published by the Pacific Northwest Forest and Range Experiment Station[1/] (Mitchell 1979, Schuller 1981).

For these six surveys each area was visited 7-10 times, depending on size and accessibility, during the growing season. On the first visit a walk through the area was done to determine the range of habitats. The RNA was then stratified and described in units that would be recognizable in the future. The number of units depended on the size of the RNA and habitat heterogeneity. On successive visits all habitats within the various units were surveyed on at least one occasion. Special attention was paid to small-scale, unmappable anomalies, such as rock outcrops, seeps, and small ponds, as these areas tend to harbor a large variety of species.

When reliable identification of species could not be made in the field, unknown taxa were collected, taken to the lab, keyed, compared with voucher specimens, and identified. Most specimens collected in the field were deposited in an herbarium. Location and habitat descriptions were included. Herbaria especially welcome specimens from RNA's because RNA's serve as permanent reference areas.

The survey publications include information on the environment and habitat or community types of the RNA surveyed. The checklist in each one includes family, genus, and species, as well as the habitats where the plants were found.

Floral surveys are often somewhat subjective. Those doing such surveys should be familiar with the flora of the region and have a feel for habitat variation, especially if the approach to sampling is nonquantitative.

ECOLOGICAL PROCESSES

Most ecological processes exhibit a lot of yearly variability (Likens 1983). Long-term records are needed to clearly understand these processes. Numerous examples exist where extrapolation drawn from two to three years of data have led to the wrong conclusions. RNA's in Oregon and Washington have provided opportunities for monitoring some ecological processes with the use of permanent sample plots, cone plots, and seed and litterfall traps.

Five RNA's have a continuous record of cone crops for periods ranging from 5 to 17 years. These plots were established where 15 to 20 tree tops could be easily detected from a trail or road. Trees were numbered with tree paint and mapped from the road or trail using a compass. Cone counts on all trees are made each year from the same spot and direction, with the help of a spotting scope. Continuous records such as these are useful in predicting cone crop periodicity and understanding the dynamics of one part of the stand regeneration process.

Tree seed has been collected for 20 years from two RNA's, one in Oregon and one in Washington, to extend our understanding of regeneration. The traps are 20 by 50 cm wooden frames with wire bottoms. Nylon mesh liners are placed on top to intercept the seed. Six to 8 traps are spaced at 10 m intervals on the forest floor.

---

[1] Cornelius, Lynn C. Checklist of the vascular plants of Sister Rocks Research Natural Area. Adm. Rept. PNW-2. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experimental Station; 1982. 8 p.

Cornelius, Lynn C.; Schuller, S. Reid. Checklist of the vascular plants of Cedar Flats Research Natural Area. Adm. Rept. PNW-5. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1982. 14 p.

Kemp, Lois; Schuller, S. Reid. Checklist of the vascular plants of Thorton T. Munger Research Natural Area. Adm. Rept. PNW-4. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1982. 16 p.

Schuller, S. Reid; Cornelius, Lynn C. Checklist of the vascular plants of Goat Marsh Research Natural Area. Adm. Rept. PNW-3. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1982. 18 p.

The liners are collected during midsummer and after spring snowmelt. The seed is sorted according to species and is counted and tested for viability.

A litterfall study of anthropogenic substances has been under way by Batelle Northwest Laboratories for nearly 7 years on four RNA's in the Pacific Northwest. Monthly samples of litter are collected from permanent collection buckets installed at each site. The litter is analyzed for nutrient content to determine the amount and kinds of airborne pollutants being intercepted by tree canopies.

A study that uses litterfall to index primary productivity on an annual basis is taking place at Wildcat Mountain RNA in Oregon. For 7 years litter has been collected from six 1 m^2 traps systematically located in the forest stand. The samples continue to be collected, and are first sorted according to twig, leaf, bark and branch, then oven dried, weighed, and archived.

VEGETATION CLASSIFICATION PLOTS

It is the responsibility of the area ecology program in Oregon and Washington to provide the National Forests with a plant community classification and predictions of site productivity. Included are the establishment of permanent photo points and sample plots that can be revisited at regular intervals. Because much of the forest is slated for future harvest cutting of some type, RNA's are among the few areas where permanent sample plots and photo points can be protected. At least 20 RNA's have been used by the area ecologists for the establishment of 30 permanent plots in 24 forest types.

Plots are established within specific habitat types. They are marked permanently in the field, on air photos, and on topographic maps. Measurements of site productivity, of wildlife use, and of basal area by species are taken. Soil descriptions and a stand density index are also included. Permanent photo points are established, and all information is entered in the Forest Service Total Resource Inventory System.

These plots provide practical information for use by the Forest Service. They also yield much data that can be used by the research and academic communities.

PROBLEMS

Establishing and monitoring permanent sample plots is only the beginning. The field work is often the fun part, but if it is not followed up by careful referencing, data organization, and some financial support the process can easily become stymied. As in any research study, objectives must be clearly defined before the study begins. One must know what and why one is measuring and monitoring. Each plot location must be well marked in the field and documented in some kind of report in the office. Procedures for data collection must be rigidly and clearly defined, so someone 40 to 50 years from now can know exactly what, how, and where things have been done. The large volume of data generated must be carefully organized. Continuous records must be maintained, updated, entered into the computer, verified, and analyzed. The data need frequent analysis in order to detect inconsistencies, omissions, and problems.

Botanical baseline monitoring takes time, money, and people. Convincing managers, directors, rangers, supervisors, and program coordinators that this kind of work is worthwhile can itself be a large task. One of the best ways is to make sure that the benefits of monitoring programs are known to the scientific community and to managers. Nothing is more convincing than actual use of such programs and the data they provide.

In the Pacific Northwest scientists have just begun to gather baseline data on RNA's. Ninety-five percent of the monitoring programs are west of the Cascade Range, and 99 percent of these are in forested stands. Botanical baseline monitoring programs are also needed for thousands of acres of shrub-steppe, desert, and other nonforest vegetation in RNA's.

CONCLUSIONS

Baseline data collection is often viewed as merely descriptive or as number gathering with no purpose in mind. Presently the huge natural landscape of the west is being altered by a resource management that tends to significantly change the natural world. As this is happening it becomes more and more important to know what is being lost, and to understand the patterns and processes of a rapidly diminishing natural landscape. In the face of these changes, baseline monitoring becomes all the more important.

Well-documented baseline monitoring should be a long-term goal. We need to have well organized and related sets of data that identify ecosystem components and how they function. This is especially true for ecosystems that have not yet been altered by management activities. This is not to say that short-term projects are not important; rather, such projects should be interactive with a long-term goal--understanding and documenting the baseline.

PUBLICATIONS CITED

Likens, Gene. A priority for ecological research. Bull. Ecol. Soc. of Amer. 64(4): 234-243; 1983.

Mitchell, Rod. A checklist of the vascular plants in Abbott Creek Research Natural Area, Oregon. Res. Note PNW-341. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1979. 18 p.

Schuller, S. Reid; Frenkel, Robert E. Checklist of the vascular plants of Steamboat Mountain Research Natural Area. Res. Note PNW-375. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1981. 20 p.

LONG-TERM MONITORING OF SMALL VERTEBRATES: A REVIEW WITH SUGGESTIONS

Curtis H. Halvorson

ABSTRACT: Vertebrate monitoring should consist of following long-term (≥ 10 yrs) patterns of relative abundance and distribution. Examples of long-term study reveal natural population variability and deficiencies in short-term study. Index methods that express animal abundance relatively, and as detections per unit measure, are suitable and outlined. Recent experience suggests that combinations of methods can be very effective for herptiles (amphibians and reptiles) and small mammals. Rodent populations should be monitored to cover annual high and low levels, and unconventional techniques should be considered. Biases are different in determining bird abundance than for other vertebrates. Recent monitoring literature is reviewed, and the mistake of assuming animal presence to represent animal needs is discussed. Monitoring plans should relate to the expected frequency of natural events, with accessory information and pilot study necessarily included. Information needs are suggested.

INTRODUCTION

Monitoring is a temporal procedure for collecting information. A baseline is the thing we measure differences or changes against; and change, according to Lund (1983), is movement of an object over time. The movement could be the rate of root penetration by a ponderosa pine seedling, abundance and reproductive success of peregrine falcons over time, or board foot increase in a forest to rotation age.

Our concept of monitoring depends on why we do it. If we monitor where people practice husbandry or resource management, then monitoring is tracking the stock on hand for a chosen objective. Then we monitor to know when we have achieved, or perhaps overachieved. This contemporary concept has been expressed in a general, a social (Bell and Atterbury 1983:664;227), and a biological (Salwasser and others 1983) context. By contrast, monitoring on a research natural area (RNA) requires that natural processes dominate; we do not instigate change and we seldom use the feedback to fine tune our actions. The definition of monitoring Franklin and others (1972) applied to natural areas was "...observing change in some aspect of the ecosystem over a period of time." That definition suggests a more passive activity - measuring bog progression or counting bird numbers and species.

I will talk about efforts that document the distribution and relative abundance of vertebrates. This follows the natural area monitoring definition. Natural fluctuations occur in all organisms but we seldom pursue our monitoring of wildlife long enough to know what the baseline is, i.e., if the variation associated with disturbance is within or beyond standard deviations of natural change. I present examples of "normal" variation in animal numbers, then outline methods to assess change and considerations in applying them, and finish with suggestions for needed information. Important elements of monitoring in natural areas include using the simplest applicable methods, a commitment to careful documentation and long-term continuity, and incorporating some complementing environmental information into the process.

Fourteen years have passed since enactment of the National Environmental Policy Act (NEPA, PL 91-90) - a progenitor of our mandate (Salwasser and others 1983) to assess, appraise, inventory, monitor, and report on our natural resources. Recently the proceedings of two international resource conferences were published: a session of six papers in the 48th North American and Natural Resource Conference, and 182 papers at an Oregon meeting (Bell and Atterbury 1983). These conferences dealt with inventories and monitoring in managed habitats (disturbed ecosystems), i.e., the feedback type of monitoring. They reflected that we are at the stage of describing our maturing experience with monitoring. Many studies were quite recent and represent appraisal and reappraisal (Hinds 1983; Hirst 1983; Raphael and Rosenberg 1983; West 1983). Two earlier papers (Hilborn and Walters 1981; Romesburg 1981) are critical of our science and worthy of reading prior to embarking on monitoring and assessment programs.

The terms modeling and multiresource inventory were emphasized in many papers. Romesburg (1981) defines modeling as an informed guess, a mixture of knowledge and error, about a process of nature. Among modelers there are five or six kinds, not all with standardized labels (see Hirst 1983; States and others 1978:B-38-39). Two broad categories exist: the deterministic or analytical model based on known or accurately

Curtis H. Halvorson is Wildlife Research Biologist, USDI, Fish and Wildlife Service, Denver Wildlife Research Center, Ft. Collins, Colo.

described elements; and the simulation, stochastic, or predictive model that mimics a real system and draws heavily on assumed or hypothesized relationships. The deterministic model gives indirect but accurate answers. The simulation model gives direct but inaccurate answers (Romesburg 1981; Hirst 1983). Many of the conference papers focused on multiresource (i.e., multispecies) inventory (see Davis 1983). Modeling proposals and efforts associated with multiresource study (Bell and Atterbury 1983) relied heavily on assumed dependencies based on species-habitat associations, rather than experimentally derived determination of actual dependencies. A preoccupation with simulation modeling does not appear to lend itself to accountability down the road. We may be obscuring the point that predictive models are only planning tools, not scientific evidence per se. These distinctions are seldom clarified. A remark attributed to Frank Egler (Jenkins 1977) was: "Ecosystems are not only more complex than we think, they are more complex than we can think." We can become swamped with untested hypotheses and decision makers may be attracted to increasingly elaborate and expensive predictive tools that could be masking truth. Models are often based on short-term studies that only identify associations. Wagner (1974:1492) states"...my concern [is] that the risks of incongruence between models and reality grow as the former becomes increasingly abstract. Hence, we need to maintain vigilance based on solid empirical foundations while at the same time pressing forward with analytical efforts...".

EXAMPLES OF LONG-TERM MONITORING

We monitor a system to learn of patterns; to recognize long- and short-term trends and marked deviations from norms. Perhaps the longest term monitoring efforts on vertebrates are found in human demographic records — the vital statistics listing births and age at death.

The data on natural variation obtained from baseline monitoring can be seen in selected examples of long-term (>5 years) tracking studies. The examples show that the 1- to 3-year efforts typical of our inventory and appraisal programs seldom bracket the natural range of variation in species composition and abundance, rarely document extremes, and can hardly verify patterns. The duration of monitoring should encompass the natural variation in the organisms or system under study.

1. Animal communities are not static and they vary in both numbers and species.
   a. There was a 23-fold difference between peak and low numbers in snowshoe hares (Lepus americanus) during a 15-year study (Fig. 1) and a 13-fold increase in deer mice (Peromyscus sp.) over 2 years in a Michigan hardwood forest (Sexton and others 1982).
   b. During a 17-year monitoring of small mammals, using the simplest method (20-station kill-trap lines), seven species were caught in 1 year, one was caught in 1 year, and either three or four were taken in 11 years. Variation in species diversity can be large in simple severe habitats such as the salt desert shrub location of this study (Reid, unpublished)[1].
   c. The highest population growth rates and densities in a red-backed vole (Clethrionomys rutilus) study did not show up until years 10 and 12 (Mihok and Fuller 1981).

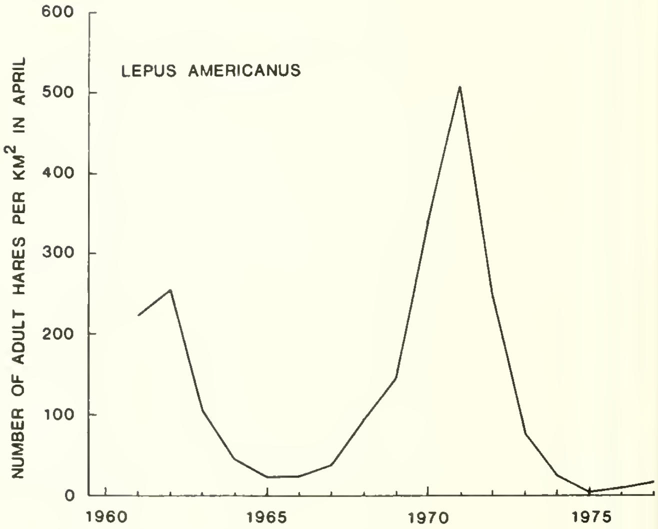


Figure 1.-- Cyclic fluctation in snowshoe hares (Lepus americanus) in Alberta, Canada (Keith 1983).

2. We are often misled about animal communities if we only sample in 1 or 2 years.
   a. In an uncut forest (Fig. 2-A), a vole (Clethrionomys gapperi), a mouse (Peromyscus maniculatus), and a chipmunk (Eutamius ruficaudus) had different levels of abundance in two pairs of years. In 1969-70 their respective proportions in the catch were 75%, 4%, and 18% while in 1973-74 they were 10%, 30%, and 52%, respectively (Halvorson 1982, and unpublished). It is understandable why apparently similar studies often disagree and many wildlife-habitat associations studies can be unreliable indicators. Yet any year of the eight studied on a clearcut burn was consistent with Peromyscus dominance (Fig. 2-B).

[1] Reid, V.H., Ft. Collins, Colorado: Data on file at Denver Wildl. Res. Ctr. Field Station, U.S. Fish and Wildl. Serv.

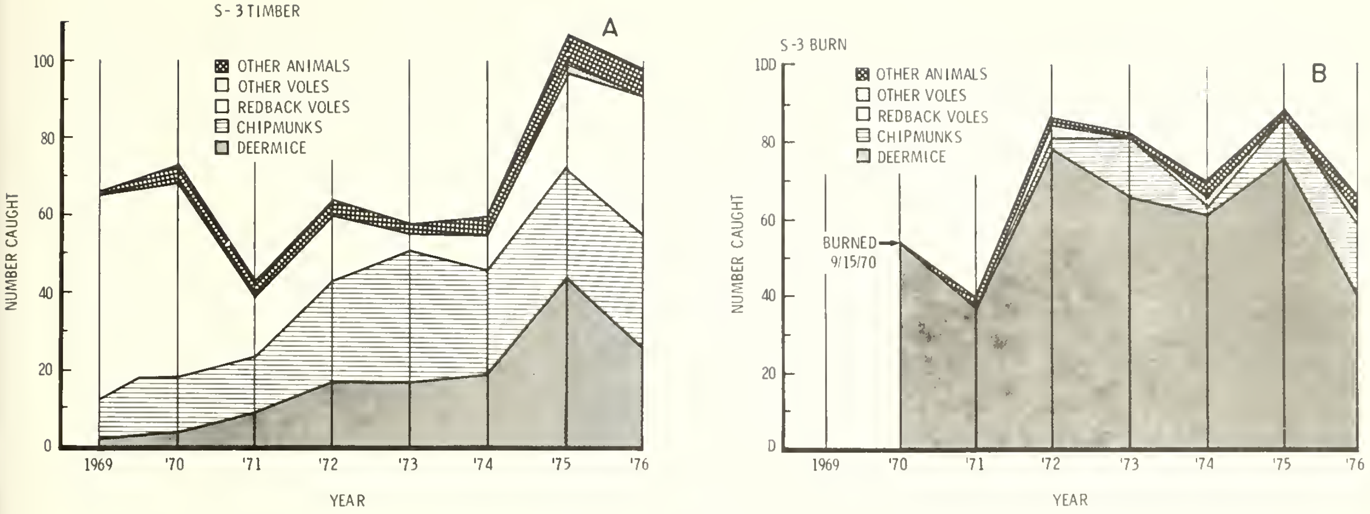


Figure 2.--Two examples of species relative abundance illustrate typical variation that can occur between years on the same plot: A) large variation in a north aspect uncut larch-fir forest; B) little change on a thoroughly burned, south aspect larch-fir clearcut (Halvorson 1982 and unpublished).

3. The ability to recognize patterns can only come from extended monitoring.
   a. An English study of species-habitat associations was conducted for 20 years (Southern 1979). Two rodent species averaged 20 per ha and fluctuated regularly about a mean.
4. Habitat-wildlife associations may not be apparent until a trend in abundance is obtained.
   a. The Canadian breeding bird survey showed a 10-year decline in five bird species that are normally associated with woodland edge and seral vegetation stages. The surveys were made in an area where agricultural land was reverting back to a closed forest canopy. An increase in red-winged black bird numbers was accompanied by increased corn acreage and a behavioral shift by birds from marsh to upland nesting in response to wetland drainage (Erskine 1978).
5. Natural events must be allowed to fully occur, especially if extrinsic factors are implicated.
   a. It took 15 years to observe 1.5 cycles in snowshoe hare abundance, or one increase and two declines (Fig. 1).
   b. Because tree seed crops are not predictable or necessarily in synchrony, it took 12 years for crop failures and abundance to be repeated by two conifer species, allowing comparisons to be made with red squirrel (Tamiasciurus hudsonicus) population fluctuations (Fig. 3; Halvorson, unpublished)[2].
   c. Red-spotted newts (Notopthalmus viridescens) breed in ponds but their young leave to mature on land. Fidelity to their birthplace is the fashion of salamanders, as for birds, eels, and salmon. After 6 years none of 800 marked newts showed up and were presumed lost, however in the seventh year and beyond, marked newts appeared. The biologist found these newts don't sexually mature for 4-8 years (Likens 1983).

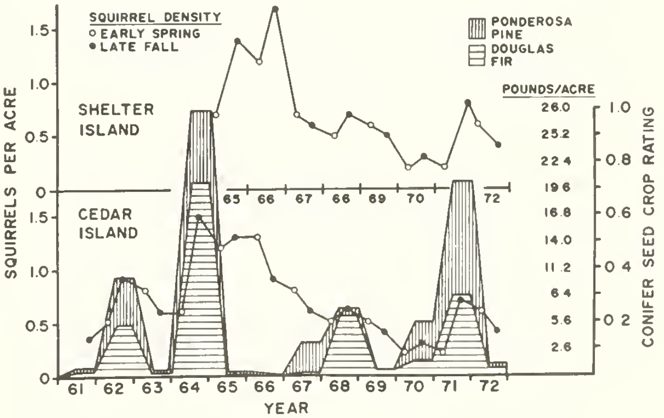


Figure 3.--Abundance patterns in two components of a Montana forest ecosystem-the red squirrel (Tamiasciurus hudsonicus) and seed crops of two conifer species - over time (C.H. Halvorson, unpublished).

[2] Halvorson, C.H., Ft. Collins, Colorado. On file at Denver Wildl. Res. Ctr. Field Station, U.S. Fish and Wildl. Serv.

DESIGN AND SOME CURRENT EFFORTS IN BASELINE MONITORING

Four design elements are essential to an ecological monitoring program (Hinds 1983; Hirst 1983; Likens 1983; Stankey and others 1983; Verner 1983): (1) long-term to bracket variability, (2) statistically valid and sensitive to trends, (3) cost effective, and (4) ecologically appropriate. Monitoring in a RNA is not a short-term tactic calculated to solve a temporary problem; it is a long-term strategy. Unlike monitoring in impacted areas, the time-frame for discerning trends and change in an RNA need not be artifically confined to a fixed pretreatment period that restrains data analysis to that available at the scheduled end-point, often a brief 1-3 years. Likens (1983) identified monitoring as a continuing objective whose overall purpose is to learn enough about systems to formulate meaningful and falsifiable questions. The inventory of patterns developed by long-term monitoring is capital gain. Statistical considerations center on detecting and comparing change over time, and deal with adequate replication. sample sizes, and stratification. Nonparametric analyses are often more appropriate. Mihok and Fuller (1981:2277) used such tests on vole fluctuations, based on catch per unit effort using kill-trap lines. Nowadays design can have legal implications if an economic or esthetic resource is concerned. RNA's can also serve as natural controls in the experimental design of monitoring programs, though routine monitoring can be a valuable part of ongoing management (Hilborn and Walters 1981). Good monitoring design relates sampling frequency to animal life history; i.e., ground squirrels are above ground only 4 months of the year and herptiles may be especially active after rainstorms. Dawson (1981a) covers factors to be considered in bird counting.

Cost effectiveness often influences study design through budget-partitioning decisions to accomplish goals (see Verner 1983). Costs become critical in proportion to the imperative for minimizing uncertainty of a prediction (Salwasser and others 1983). Great Blue Heron nesting garbage was finally selected as the estimator for environmental contaminants after a very structured search for the most efficient method (Carlile and Fitzner 1983). If natural area monitoring is mostly a continuing program that emphasizes species inventories and population trends, then the decision risk is low, and permits simple, frugal techniques. Raphael and Rosenberg (1983) reported on cost-effectiveness of six methods to inventory forest biota. Live trap grids were the most costly, at $45.00 per sample plot per species detected. Variable circular bird census plots were the most cost-efficient at $2.00 per plot per species detected. Abundance determinations, as opposed to simple detections, raised costs proportionately. Pitfall traps were singularly efficient ($8.65) in taking shrews, moles, herptiles, and uncommon mice. Baited, sooty, tracking plates ($7.54 per detected species) recorded nine species not otherwise recognized. The impact of destructive versus benign methods (litter search vs. pitfalls for amphibians) should be considered. The relative costs of detecting common versus rare species is analyzed by Marcot and others (1983). Verner's (1983) cost-effective decision was to monitor birds because they were the most conspicuous vertebrate, and to search only at a level necessary to detect decline because increases were not of management concern. As a next step, he advocated that the most cost-effective monitoring could be obtained by substituting trends in habitat condition diversity for direct species monitoring. A feedback loop would eventually reinforce the knowledge of species habitat needs such that habitat alone would reflect species status. A related assumption was that the stability of birds, grouped by management guilds in sensitive habitats (riparian, meadow edges, mixed conifer), would reflect the stability of other taxa, e.g., mammals and herptiles.

Questions arise as to these proposals. My personal concern is an uneasiness with a prevalent mind set on multiresource monitoring. This keeps repeating and confusing wildlife-habitat associations with wildlife species needs. "...A near universal premise of the models (wildlife-habitat relationships) is that the distribution and abundance of wildlife species may be presumed from habitat components" (Marcot and others 1983). To assume that tracking bird population trends will signify to us which way entirely different classes of organisms will go is a magnificent presumption in light of our present scanty knowledge of an animal's specific critical needs.

The fourth design element, ecological appropriateness (Hinds 1983), requires that our assumptions about ecological relationships be valid. Confusing species associations for dependencies was implied or expressed in many of the symposium papers (Bell and Atterbury 1983). Recognition of the difference was rare. Therefore, it seems we are still very much in a state of perceived rather than proven relationships between a species and where it occurs. Yet perceived relationships are the basis of our Habitat Models (O'Neil and Schamberger 1983). According to Paine (1981) many, if not most, fundamental interactions between a species and its environment are nonlinear and the exercise of some free choice by mobile species adds "noise" (i.e., can confuse predictive models trying to relate to the real world).

The conferences of 1983 reported recent efforts or plans to relate wildlife species abundance to habitat features. Attempts to link Forest Inventory Surveys and wildlife resource assessment were described, but the findings were inconclusive. Morrison (1983) decided that more habitat variables were necessary, beyond the 13 he used to predict timber growth and volume, because those left 65-85% of variation

unexplained. Yet when 270 timber and habitat descriptors were measured (Porter and others 1983), 90% of the variance was accounted for in 10% of the factors. Replicated year sampling was advised. A study evaluating HSI's (Habitat Suitability Indices) to monitor wildlife only measured two variables (cover and height) of three floral life forms in a 3-month study. The results were inconclusive and another study covering at least 2 years was suggested (Cole and Smith 1983). A 2-year progress report (Raphael and Rosenberg 1983) on multiresource inventory had two dissimilar years of bird inventory data and concluded that there is no surrogate for long-term replicated study.

Short-term, one- or two-season, multiresource inventories usually monitor easily measured physical variables from which sophisticated predictions are made, but temporal variability is certainly a characteristic of vertebrate populations. The species-specific sampling techniques of Raphael and Rosenberg (1983) gave positive results and indicate the effectiveness of incorporating behavior. Managers will not recognize the consequence of their decisions if they are led to believe an animal's function and address are the same. The interactions between animals, their food, space, competition, and behavior do need far more delineation before mathematical relationships with habitat variables can be assumed or achieved (Pielou 1981). Studies reported at the meetings discussed above recognized that fact to varying degrees.

For very common species it is possible to accurately predict their presence, or even their abundance, from secondary indicators such as vegetation type or structure. But rare creatures are much more sensitive to limitations in their environments and we need precise knowledge, beyond an association, of their needs (Jenkins 1977).

Finally, requirements for good design can sometimes be met empirically. Eighty ha (200 acres) of ponderosa pine, among many thousands on a certain Wyoming mountain, serve as a winter roost for two eagle species. Explaining the use of that special 80 ha is "...a prairie hunting ground, well grazed and normally blown clean from stormy westerly winds, with a river close by covered with ponderosa pine for roosting, where there is an evening updraft to an undisturbed ridge that slopes westward toward the hunting country" (Kerr and Brown 1977) -- allowing an energy-efficient glide to breakfast the next morning.

But this explanation has not been tested, therefore is only conjecture without a probability statement. It does represent a synthesis of careful and prolonged observation by curious people who were interested in eagles and could conceive of relationships because they had lived and worked amidst natural interactions a long time. What single element or minimum combination makes eagles use that 80 ha? Logic and truth are not synonymous and proving the hypothesis might not be worth the cost, even if testing were possible. We can't divert the prevailing winds and clear-cutting the west rim could not be worth validating a prediction, but the process by which the Jackson Canyon eagle presence is explained should also be considered a valid, and cost-effective, and ecologically appropriate design for monitoring. Observational design is also appropriate for studies in research natural areas.

METHODOLOGY

Monitoring in research natural areas versus managed lands differs chiefly in the application of findings rather than in the methods used. We rely on the same pool of techniques for estimating wildlife populations.

I will cite several recent references that represent major literature searches. Some are relatively inexpensive or available as agency publications. There are also excellent accounts on regional species' biology (e.g., Maser and others 1981).

A broad scope of methodologies for vertebrates is found in Schemnitz (1980), Call (1981), Miller and Gunn (1981), and States and others (1978). Davis' (1982) book is a unique (but very expensive) collation of various workers' recommendations. It is based on their published studies and is both species- and habitat-specific, with discussions of over 100 species. Small mammal study is comprehensively treated by Golley and others (1975). Herptiles are covered in Scott (1982) and some of the previously mentioned works. The most recent complete coverage on birds is edited by Ralph and Scott (1981). Short papers by Mannan and Meslow (1981) and Martinka and Swenson (1981) give concise evaluations of counting methods for nongame and upland game birds, respectively. Call (1978) on raptor surveys, Franzreb (1977) on general bird inventorying, and Mikol (1980) on field application of bird transects are useful. Publications that integrate habitat with wildlife include U.S.D.I. Fish and Wildlife Service (1977), Flood and others (1977), and Short and Burnham (1982). Progress towards an ecological land classification is reported by Driscoll and others (1983). Caughley (1977) treats the analysis of population data as do articles in Ralph and Scott (1981) for birds. Finally, Delaney (1974) summarizes methods, results, and opportunities for small mammal ecological study.

The uncertainty of choosing the correct method to determine species abundance in a research natural area is diminished by knowing there is no correct method for birds, mammals, or herptiles. A "wrong" approach would be selecting an unnecessarily precise and expensive procedure. However, if a rationale is needed for selecting a census method, Garton (1981) shows a dichotomous procedure, based on critical questions about the populations. Absolute density estimates (individuals per unit of area)

are necessary in certain ecological studies (e.g. food chain or contaminant energetics, disease transmissions), but are seldom needed for baseline inventory. A complete count of any wild population has rarely been achieved. The density figures presented in literature are often derived estimates based on violated assumptions. To compare between populations or between years, an index of relative abundance, numbers caught per se, or catch, sight, or sign per unit effort is felt to be as meaningful, but more economical, as correlates of density (Caughley 1977:12; Mannan and Melsow 1981; Dawson 1981 b,c; Emlen 1981).

Amphibians And Reptiles

Herptiles are suitable but neglected candidates to monitor because they often have limited movement, strong fidelity to shelter and breeding sites, and can be sensitive to environmental changes. Their abundance is quickly enhanced by a rain, offering opportunistic options for detection with the proper conditions. Their ecosystem relationships are not well known (States and others 1978), but they can be an abundant segment of forest fauna (Scott 1982). Bury and Raphael (1983) report 400 to 3,000 salamanders per hectare. The behavior of herptiles can also make abundance estimates difficult. They are secretive, frequently nocturnal, well camouflaged, often swift, fossorial, and seasonally or geographically inactive for long periods (Heatwole 1982). Small mammals have similar characteristics.

Proven experience with a combination of old and new censusing methods is succinctly explained by Bury and Raphael (1983). Results are available from Pacific Northwest old-growth conifer forests (Raphael and Rosenberg 1983), mesic and upland Florida habitats (Campbell and Christman 1982), and deciduous forest and field environments in Wisconsin (Vogt and Hine 1982). These studies used pitfall and funnel traps with drift fences to channel animal travel. Pitfalls were particularly efficient for herptiles and also for certain rodents and shrews (Raphael and Rosenberg 1983; Williams and Braun 1983; R. Bury, pers. comm.). Pitfall trapping, if used as a removal sampling method, has potential for altering population structure because it is very efficient. Herptiles are usually long-lived and have limited home ranges. The best method of inventorying, according to Bury and Raphael (1983) utilizes pitfall arrays in combination with physical search methods. Results can be expressed as capture rates per plot searched, number caught per day or per unit length of drift fence (Vogt and Hine 1982), or biomass. Extrapolation of biomass is cautiously advised because herptiles commonly show clustered distribution. The minimum area needed to conduct searches and inventory depends on the species. For example, terrestrial salamanders usually occupy small home areas (<100m^2), but migratory forms may travel >1 km to breeding ponds. The overall size of herptile plots can often be a fraction of standard-sized bird or mammal areas. Most herpetological studies center on plots of 1-5 ha.

Mammals

Baseline monitoring of small mammals usually entails direct counts, such as by trapping. Trapping allows access to sex, age, and reproductive status of populations. Some direct count methods, night-lighting for lagomorphs or ferrets, can only show numbers observed. Direct count expressions of abundance can be numbers of individuals or captures per unit effort (catch per 100 trap-nights), with biomass a secondary but integrating figure. Indirect counts of sign sometimes may be the best available technique. Ungulate or rabbit pellet groups and coyote scat or scent station visits (Griffith and others 1981) are compared as sign per plot or distance travelled.

Relative abundance for the fossorial pocket gopher (Geomyiidae) can be compared with indirect counts (Reid and others 1966; Anthony and Barnes 1982). I have used indirect counts based on 0.05 ha (0.12 a) circular plots. Pocket gopher mounds are flattened and 48 hr later any new digging evidence is counted as an active plot. Relative density is expressed as the number or percent of plots having sign. Plots are spaced at 15.2 m (50 ft) along a transect, the distance reasonably assumed to separate individuals. Plot area should represent 5% of the site at minimum. Sampling is best done when activity is high, usually in late summer when young are forced from the parental burrow and are establishing their own tunnel system.

Small mammal monitoring with traps is particularly dependent on animal behavior - the sample coming to the collector. An index line of traps is the simplest, most meaningful and economical approach to long-term monitoring for comparing differences in numbers between seasons and areas (Linn 1963; Linn and Downton 1975; Southern 1965; Petticrew and Sadleir 1970). Index lines, circles, or groups of trap clusters (Hansson 1967; Peterle and Giles 1964) provide not only the minimal inventory information such as relative species occurrence, but also long-term abundance and reproductive patterns (Mihok and Fuller 1981). The results depend on how intensively the effort is applied and whether live or kill traps are used. Index lines, in tests against grid-determined density estimates, have produced sufficiently precise results to warrant their use as a convenient substitute. If used in conjunction with assessment lines, comparable and reliable density estimates have been obtained (Petticrew and Sadleir 1970; Smith and others 1975; O'Farrell and others 1977; O'Farrell and Austin 1978). A common index line configuration uses 20 stations per line, with stations 10-15 m (33-50 ft.) apart, and two to four traps placed within arm's length of each station point. A shorter spacing of 5 m (16 ft) is often used for voles. Bock and Bock (1983) advise paired lines but Whiting and others (1983) used 3 transects

per sample unit. Linn (1963; pers. comm.) used a short dense arrangement of 50 live traps in 10 clusters of five traps spaced 5 m apart. The lines were only 45 m (148 ft) in length and operated for a single 24-hr period, the rationale being to extract a time-specific sample before any population changes occurred. Southern (1973) also used a 24-hr period but with a grid and dense trap clusters. A 24-hr period attempts to fulfill the assumptions of closure, i.e., no birth, deaths, or movements in or out of the population. Some rodents, particularly young, travel in pairs, and if not caught simultaneously (Feldhammer 1977; Jenkins and Llewellyn 1981) in the same trap, there must be provision for same station capture. Several traps per station are normally used to minimize overload and biased sampling. Hansson (1967) advised 5 to 10 traps per station. If ≤80% of traps were occupied, Southern (1973) felt he had an adequate number.

The choice of trap type, live or kill, has ramifications. Heterogeneity in catchability can be associated with species and age (Jolly and Dickson 1983). Suggested compensatory procedures include using combinations of live, kill, and pitfall traps (Peterle and Giles 1964; Beacham and Krebs 1980; Raphael and Rosenberg 1983; Williams and Braun 1983); extended trapping periods; and experimenting with baits (Beer 1964; Patric 1970; Sullivan and Sullivan 1980). Peanut butter mixed with rolled oats has been a standard bait, effective for most situations. It is a common and useful practice to also include whole oats or sunflower seeds, particularly if voles are present. Their survival (in live traps) will be enhanced. For kill-trapping, usually two Museum Special mouse traps and one rat trap are set per station. Pitfall traps will probably be increasingly incorporated because of their efficiency (Beacham and Krebs 1980), despite greater cost to install (Raphael and Rosenberg 1983). Kill-traps operated no more than three consecutive 24-hr periods will reduce opportunities for animals nonresident to the line's area of effect from being drawn in as residents are removed (Southern 1973; Johnson and Keller 1983a). The actual area a snap-trap line affects remains in question (Johnson and Keller 1983b). Yang and others (1970) explored the problem on two vole species without reaching a conclusion and few studies have been done since. It has been conventional wisdom that kill-trapping once or twice a year for short (3 days) periods could have little impact on highly fecund rodents. However, there has been concern (L. Metzgar, pers. comm.) and evidence (Metzgar 1971; Mihok 1979; Webster and Brooks 1981; Clulow and others 1982; Jannet 1982) that some rodents have a well-developed social structure such that removal, especially of important reproductive members of a population, can alter subsequent breeding patterns, age structure, and behavior among young and females (Van Horne 1981).

The question of snap-trapping repeatedly in the same areas is not resolved, but the most complete and rapid determination of population patterns comes from live-trapping that is repeated during high and low periods of an annual cycle, as West (1982) did on the red-backed vole (C. rutilus). Otherwise, with once per year trapping a minimum or maximum can only be assumed, not identified. To do repeated trapping, in light of the previous consideration, I suggest live-trap index lines or trap-groupings applied during a breeding period, usually the low point and in spring, and again during the post-breeding period, usually the high point occurring in fall (Terman 1968:420). This approach can provide comparative numbers, relatively undisturbed age structure, and indicate breeding status. Adding assessment lines can yield density estimates if required. Sampling timing should recognize seasonal breeding patterns associated with latitude and moisture — the "northern" and "southern" breeding cycles. Trapping duration is a compromise between long enough for maximum trap exposure for residents, but short enough to avoid stress on animals. Five or 6 days is common; less time may produce small samples. Extending a trapping period is not advisable because repeated handling causes stress and weight loss, particularly during inclement weather. Live-trapping stress can be reduced by minimizing the time animals are confined. Most trapping is conducted once or twice a day. Disadvantages are that the species, particularly diurnal ones, will be confined for lengthier periods than their normal activity, depending if they enter a trap at the end of their daily cycle; e.g., a chipmunk caught at sundown. Voles are active day and night but they have poor survival from long confinement. I suggest a seldom-used technique that can enhance survival and increase trap availability and effort without increasing trap quantities or sampling duration. It employs two trap checks made during darkness, one prior to midnight and the second ending in the hour of first reading light. Using this approach in aspen habitat, I caught 97% of live-trapped and 100% of kill-trapped deer mice during darkness hours. About 90% of the chipmunks were caught between 0900 and dusk (Halvorson, unpublished)[3]. Area size will determine index line distribution and configurations. Paired lines, 100 m apart with a 100-m end buffer zone and using 20 stations at 15 m spacing, would occupy about 13 ha (33 a) or a rectangle 282 m by 470 m (311 by 516 yd) in forest. Index lines in riparian habitat might be spaced end to end with only a 50 m lateral buffer and still represent the zone. But a 3 ha (7.4 a) meadow would barely contain two lines of 10 stations each without intruding on edges. One solution is to use shorter, circular lines

[3] Halvorson, C.H., Ft. Collins, Colorado. Manuscript on file at Denver Wildl. Res. Ctr. Field Station, U.S. Fish and Wildlife Serv.

with the possibility of reduced sample sizes. Another is to describe and sample the area as a mosaic, but this technique may cloud data interpretation. Although sampling in uniform habitat is desirable and statistically necessary for studies that test treatment effects, the baseline inventory purpose of RNA monitoring could be less structured if the following are observed: 1) consistent methods are applied on permanently marked plots in a standard time frame; 2) sites are described in conventional terms used for habitats. With these guidelines unconventional or nonstandard sampling patterns could be used when needed because the primary comparison would be within sampling units between years.

A second but unconventional configuration and dispersion of sampling units is suitable if the above standards of consistency and site description are used. The method apparently was developed by Patric (1958) and applied by Peterle and Giles (1964), but has rarely been used. Some principles of the method were independently suggested and used by Hansson (1967). "Rosette" clusters of eight live traps were distributed in an approximate stratified grid. The clusters were spaced 61 m (200 ft) apart and traps evenly placed in a circle within 1.5 m (5 ft) of a point (station). The wide space between stations was intended to reduce trap station interaction. Patric (1958:163) referred to a "critical trap interval.... the minimum spacing at which traps cease to compete for a small mammal with a given cruising radius." The commonly used 10-15 m station spacing is well within most rodents' usual travel and traps do compete. Hansson (1967) recommended index lines of widely spaced (25-50 m), dense (5-10 traps) clusters, but additionally used a large radius (5 m) about each point to set traps within, and a single 24-hour setting as a precaution against change in the population. The intent of these wide spacing methods is to extract noninteracting samples from an area. Interaction may occur at each trapping point but this distributed-spot method has more merit for pattern flexibility than long lines and is worth testing. If kill-traps were used in distributed spots of 8-10 traps, and stations moved within the site condition each season and year, the area of effect would theoretically be diffused and disturb populations less than repetitive trapping at the same location along permanent lines. The concept of dense trap clusters widely spaced, using pre-baiting, and index trapping for a brief period, merits consideration for natural area use.

Birds

Songbirds should be an ideal subject to monitor. They are evident by sight and sound and their presence is predictable — daily and seasonally — during migration and breeding periods. In contrast to inventorying small mammal populations, only binoculars and data sheets are necessary equipment. However, the information obtained from bird monitoring techniques is severely limited and you should not expect more than species identification and presence. You cannot tabulate physical characteristics to associate with changes in an abundance index. If small mammals do not enter your data field (trap), you are either absolved or productive because they control your access to them and they register themselves as too scarce to be counted, if not caught. With bird counting a good portion of some eight biases associated with measurement error (Dawson 1981b) may be with the observer (McDonald 1981) and you bear the onus of weak data. For this reason observer error should be controlled and other variation minimized by standardizing the conditions of season, day, and time when monitoring. Individual bird and species behavior and the effects of habitat on detectability cannot be controlled, but might be estimated (Ralph and Scott 1981:252-261). Ralph and Scott (1981) is the primary reference for a bird monitoring program. An overview of counting methods is summarized by Mannon and Meslow (1981) for songbirds, and Martinka and Swenson (1981) for game birds. I will only mention a few general considerations.

There is a more realistic opportunity to approach an absolute census of birds than for rodents. Most song birds are conspicuous and exhibit territorial behavior during the breeding season. A spot mapping technique (Audubon Field Notes 1970) uses repeated visits to a plot where each detected bird is marked on a map, and the cluster pattern of individual locations gives territorial boundary limits translatable to density. But this method is very costly in time and not error-free (Dawson 1981c).

It was reassuring to read Emlen (1981): "...that indices of relative abundance are adequate and preferable to density estimates for most if not all projects concerned with population responses..." Thus, ornithologists and mammalogists seem in harmony that indices of relative abundance are entirely suitable for long-term monitoring.

A bird abundance index is measured in number of birds detected (seen or heard) per unit effort under standard conditions of daily time, season, and weather. One approach is to count along a walking transect and present abundance as the number of birds detected per distance or time. Alternatively, a station count uses a series of fixed points when birds are counted for set time intervals and the expression is number of detections per station (Mannan and Meslow 1981). Variations of each index method exist and Ralph and Scott (1981) should be consulted. Areas larger than 10 ha (25 a) are desirable. The starting date in spring can vary and should be cued to weather and plant phenological indicators such as bud burst or early flower bloom. Phenological records of plants are available for the Northern Rockies (Mueggler, 1972; Schmidt and Lotan 1980). A cold wet spring can delay migration and nesting for weeks, and also the availability of insects that most birds use heavily during nesting.

Dawson (1981b) suggests that monitoring design include a large number of replicates visited in standard fashion yearly. Trade-offs exist between the number of replicates per area and number of areas to be surveyed in a limited seasonal and daily time-frame. Rare species should first be located and then trends recorded at those sites rather than attempt a random sample. If habitats are not too diverse, indices can be compared if detectability biases are recognized. Topography and vegetation density and structure are but some habitat variables affecting detectability (Dawson 1981a). Raptor numbers and nesting success can be monitored by direct observation since nest sites are often reused (Call 1978; Fuller and Mosher 1981). Special precautions against disturbance must be observed. Bird counting from spring through winter is less definitive because territories break up, young are transitory, and birds shift their feeding areas frequently.

ACCESSORY INFORMATION FOR VERTEBRATE MONITORING

Information on the conditions and circumstances under which populations are sampled is an invaluable record. The conditions at sampling time plus characteristics of the location are basic information. Simple weather facts pertinent to animals are inexpensively provided with a maximum-minimum thermometer, rain gauge, sling psychrometer, a wind chart or gauge, and estimates of cloud cover and moon phase. Sophisticated but expensive devices can give continuous records. Environmental influences can provide clues to population performance, as in the case where rainfall was correlated with estrogenic potency of three African grasses, an effect similar to that achieved in experimental studies with wheat and voles in the U.S. (Delaney 1974:34). Bird counting is most suitable with little wind, no or faint precipitation, and nonextreme temperature (Robbins 1981). Nocturnal rodent activity shows positive response to rainy, cloudy, moonless, warm humid nights, with temporarily reduced movement on very cold nights (Vickery and Bider 1981). Habitat features that have been related to bird and mammal presence include ground cover, plant canopy and density (also logs and stumps), and plant structural features (layering, crown volume). Duff and litter depth and soil permeability are easily measured (Kitchings and Levy 1981; Brown and others 1982). Seeds are a basic energy source for many birds and rodents, but crops are seldom measured. Seed crop production and periodicity, especially trees, are readily measured with collectors and should be included. The seed production and periodicity of shrubs and other plants should be measured. Unfortunately, there is no national system to monitor tree seed crops in forestry. A final basic need is to collect and deposit specimens of the animals studied (Finley 1980). When verified and deposited in a museum they become archival information and a critical part of the monitoring record. Such collections can be made during a pilot study.

A pilot study is a preliminary trial and evaluation of a proposed operation. Project-type resource monitoring efforts often seem unable to afford trial runs. While skillful indoor planning and relying on familiar or convenient techniques may allow full-scale implementation right from the planning stage, a break-in time might be far more cost-effective. Dean (1984) in reviewing Adolph Murie's naturalistic grizzly bear study, reflected: "...it may be worth reminding ourselves that too many do not take, or are not given, time to learn their subject before jumping into research with borrowed hypotheses, complex tools, and quantitative fragmentation. First should come enough personal experience to develop a feel for what is there, perhaps the basis for one's own hypothesis, and the knowledge as to which end of the beast to which to attach the tools." Similarly, after 12 years' experience in environmental assessments, applying state-of-art computer simulations with process and baseline studies, Hilborn and Walters (1981) acknowledge that their "good" environmental predictions more commonly arose from "some qualitative understanding" about a system's behavior and construction than they did from more expensive and sophisticated approaches. They report that the key to understanding in a spruce budworm program, where birds, trees, and the insect interacted, was qualitative knowledge about those constituents and the ecosystem where they occurred. The keys were experience and thought, things machines do not develop. A pilot study period of up to 2 years can provide a species inventory, select phenological markers, develop cost estimates and time schedules, and suggest procedures to discard before they become locked into the program.

If many organisms and systems are monitored in a research natural area, problems with scheduling the data collection have to be considered. Some work can be interspersed with a principal effort, such as bird counts and collecting seed trap contents. Also, there would be little conflict between bird and small mammal monitoring if birds were counted in spring and winter with small mammal data collected right after spring bird counts and again in fall. Habitat descriptions might fit into the summer flowering period. Since the index procedures used for vertebrate monitoring are limited to identifying patterns and presence, accessory information augments our knowledge of natural process.

INFORMATION NEEDS

Perhaps when we can construct a functioning food web in a pond or on a forest plot, we will truly know wildlife needs. We do not have that sophistication yet. The search for ecosystem understanding proceeds in sequential steps, slightly modified from Wellner (1972): 1) classification; 2) identification of components; 3) description of patterns; 4) determination of process and production; 5) delineation of factors influencing production;

6) description of pattern, productivities, and function under alternative use. Baseline monitoring in and outside of a RNA would include steps 1 thru 3. Intensive research inside or outside of a RNA would add steps 4 and 5. Step 6, would be done outside a research national area to keep intact the concept of a RNA, but it could serve as an experimental control.

I have concern for those who say we have all the information we need to manage our rescurces. That belief is sure to result in a high percentage of Type II errors, accepting a hypothesis when you should reject it. While it is necessary to plan resource management on available and predicted information, it is detrimental to safe husbandry and learning the truth if we direct the main part of our efforts to applying current wisdom to drive our models, at the expense of improving our knowledge base. Probably few really believe our information base is adequate and reliable, but some computerized wildlife data bases may give that illusion, and this is as harmful as a mistaken belief. What we really known about wildlife, especially nongame species relative to the prior six steps, is that we have a working knowledge for step 1 and 2, scattered reference material for step 3, uncertainty and little proof for 4 and 5, and essentially nothing but ax handle judgement for predicting impact (6). Yet we currently try to manage resources and make predictions about animals from information anchored in step 2 (knowing the parts and where they live), and bravely leaping the chasm of ignorance containing 3, 4, and 5 (how these parts operate together) to prophesy what happens when the system is disrupted (step 6). To paraphrase Dobzhansky (1966), an ecosystem is not a mixture of plants and animals stirred together, it is an integrated system that arose as a result of two billion years of organic evolution. Woodwell (1977) explains that natural systems have solved their problems in diverse ways; solar power, continuous yield, recirculated water, renewable nutrient fluxes, and stable (relative to time) populations.

Research natural areas, using baseline monitoring, can meet a primary information need on vertebrates, that of long-term (over 10 years) population patterns. The value of monitoring would be magnified if comparative data are collected along some gradient of moisture, altitude, or succession. A second need is to complete our habitat-wildlife association catalogues to determine what exists in undisturbed and unique situations. Third is a need for a process to integrate and display the bird, mammal, and herptile patterns that come from monitoring. A suitable display format might resemble Fig. 4, which depicts patterns for three small mammals, set against plant ground cover changes over a 100-year forest cutting rotation. This is a parts catalog that managers could use, based on long-term experience. Our present wildlife data bank programs represent a first step of mixed quality; they do not advise the consequences of management actions because we are uncertain of the relationships between impacts and the true needs of most animals.

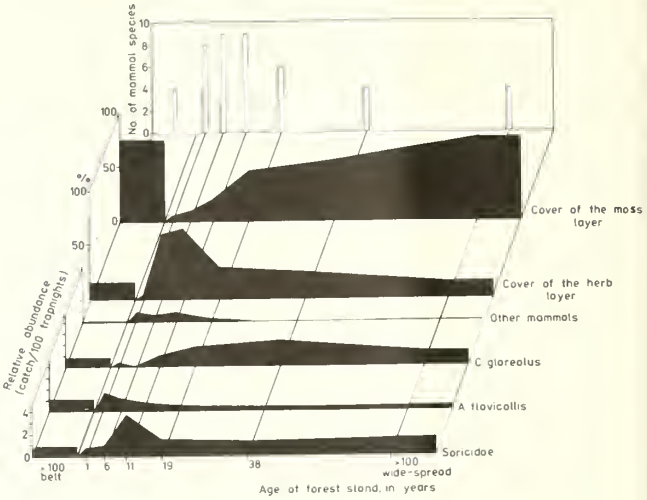


Figure 4.--A format that integrates small mammal abundance and vegetation cover with coniferous stands of different ages (reprinted by permission from Wolk and Wolk 1982).

A last and pragmatic institutional need is some provision in our career ladders and program planning to conduct long-term monitoring. A not original observation is that career payoffs are mostly in the form of specialty products that meet the current need or capture the fads. Exercise physiologists tell us that muscle fibers of sprinters are 70-80 percent "fast-twitch" muscles and those of marathoners are 70-80 percent "slow twitch." Fast-twitchers can leap chasms with a powerful energy burst, exhaust that and change directions. The slow-twitchers have to walk down one side, across, and up the other and continue the path. Each type can do a job but career awards largely go to the sprinters. We either need to give recognition to the reciprocal part of each worker or support long-distance training. Iker (1984) details the substance and style of some long-term research scientists.

CONCLUSIONS

What can we expect to get from baseline monitoring in research natural areas? We would assemble a list of species in association with each other and their habitats. Long-term patterns of population variability would be developed, along with an appreciation for "normal" variability, which is not as definable with short-term study. There would be parameters to refine models and suggest paths and relationships to explore and test. What we should not expect are absolute densities, a detailed picture of animal demographics, proof of animal habitat needs and dependencies, (except inferentially), and responses by communities to disturbance, unless a natural experiment occurred.

Certain guidelines that can facilitate the conduct and success of monitoring should be reemphasized. 1) A long term commitment to funds and personnel must be upheld. This should be part of the planning design. 2) Techniques should strive for simplicity and economy. Indices of relative abundance meet these criteria. 3) Standardized methods, applied consistently, are necessary for biological and statistical validity. Methods should match objectives. 4) Data should be suited for computer processing but not at the expense of access or visibility by less technical means. A machine should not drive out thought and experience. 5) There should be biological sense in design and data collection. 6) Accessory knowledge about the sampling environment is needed to frame the patterns as they unfold. 7) Finally, a pilot study should be allowed to explore and test so that thoughtful choices can be structured to achieve goals. Research natural areas have a unique role to play simply by existing as natural controls and serving to convey patterns, if we are serious about listening.

PUBLICATIONS CITED

Anthony, R.M., and V.G. Barnes, Jr. 1982. Plot occupancy for indicating pocket gopher abundance and conifer damage. Pages 247-255 in D. E. Kaukeinen (ed.). Vertebrate pest control and management materials: fourth symposium. ASTM Spec. Tech. Publ. 817. 1916 Race St., Phila., PA. 305 pp.

Audubon Field Notes. 1970. An international standard for a mapping method in bird census work recommended by the International Bird Census Committee. Audubon Field Notes 24:722-726.

Beacham, T.D., and C.J. Krebs. 1980. Pitfall versus live-trap enumeration of fluctuating populations in Microtus townsendii. J. Mamm. 1:486-499.

Beer, J.R. 1964. Bait preferences of some small mammals. J. Mamm. 45:632-634.

Bell, J.F., and T. Atterbury (eds.). 1983. Renewable resources inventories for monitoring changes and trends. College of Forestry, Oregon State University, Corvallis. 737 pp.

Bock, C.E., and J.H. Bock. 1983. Responses of birds and deer mice to prescribed burning in ponderosa pine. J. Wildl. Mgmt. 47:836-840.

Brown, J.K., and R.D. Oberheu, and C.M. Johnston. 1982. Handbook for inventorying surface fuels and biomass in the Interior West. USDA Forest Service Gen. Tech. Rept. INT-129. Intermt. For. and Range Exp. Sta., Ogden, UT. 48 pp.

Bury, R.B., and M.G. Raphael. 1983. Inventory methods for amphibians and reptiles. Pages 416-419 in J.F. Bell and T. Atterbury (eds.). Renewable resources inventories for monitoring changes and trends. College of Forestry, Oregon State University, Corvallis. 737 pp.

Call, M.W. 1978. Nesting habitats and surveying techniques for common western raptors. Tech. Note TN-316. USDI, Bureau of Land Mgmt., Denver Serv. Ctr., Denver, CO. 115 pp.

_____. 1981. Terrestrial wildlife inventories. Tech. Note 349. USDI, Bur. of Land Mgt. Denver, CO. 171 pp.

Campbell, H.W., and S.P. Christman. 1982. Field techniques for herpetofaunal community analysis. Pages 193-200 in N.J. Scott., Jr. (ed.). Herpetological communities. USDI Fish and Wildlife Serv., Wildl Res. Report 13. Washington, D.C. 239 pp.

Carlile, D.W., and R.E. Fitzner. 1983. Use of fauna as biomonitors. Pages 412-415 in J.F. Bell and T. Atterbury (eds.). Renewable resources inventories for monitoring changes and trends. College of Forestry, Oregon State University, Corvallis. 737 pp.

Caughley, G. 1977. Analysis of vertebrate populations. John Wiley & Sons. New York, N.Y. 234 pp.

Clulow, F.V., E.A. Franchetto, and P.E. Lansford. 1982. Pregnancy failure in the red-backed vole, Clethrionomys gapperi. J. Mamm., 63:499-500.

Cole, C.A., and R.L. Smith. 1983. Habitat suitability indices for monitoring wildlife populations - an evaluation. Trans. North Amer. Wildl. and Nat. Resources Conf. 48:367-375.

Davis, D.E. (ed.). 1982. Handbook of census methods for terrestrial vertebrates. CRC Press, Boca Raton, FL. 397 pp.

Davis, G.E. 1983. Natural resources monitoring in Channel Islands National Park. Pages 102-110 in J.F. Bell and T. Atterbury (eds.). Renewable resources inventories for monitoring changes and trends. College of Forestry, Oregon State University, Corvallis. 737 pp.

Dawson, D.G. 1981a. Experimental design when counting birds. Pages 392-398 in C.J. Ralph and J.M. Scott (eds.). Estimating the numbers of terrestrial birds. Studies in avian biol. No. 6, Allen Press, Lawrence, KS. 630 pp.

_____. 1981b. Counting birds for a relative measure (index) of density. Pages 12-16 in C.J. Ralph and J.M. Scott (eds.). Estimating the numbers of terrestrial birds. Studies in avian biol. No. 6, Allen Press, Lawrence, KS. 630 pp.

_____. 1981c. The usefulness of absolute ("census") and relative ("sampling" or "index") measures of abundance. Pages 554-558 in C.J. Ralph and J.M. Scott (eds.). Estimating the numbers of terrestrial birds. Studies in avian biol. No. 6, Allen Press, Lawrence, KS. 630 pp.

Dean, F.C. 1984. A review of the "Grizzlies of Mt. McKinley." Defenders of Wildlife 59:38-39.

Delaney, M.J. 1974. The ecology of small mammals. The Institute of Biology's Studies in Biology, No. 51. Ed. Arnold, Limited, 25 Hill Street, London. 57 pp.

Dobzhansky, T. 1966. Are naturalists old fashioned? The Amer. Naturalist 100(915):541-550.

Driscoll, R.S., D.L. Merkel, J.S. Hagihara, and D.L. Radloff. 1983. A component land classification for the United States. Status Report. USDI, Bureau of Land Mgmt., Denver, CO. 30 pp.

Emlen, J.T. 1981. Summary of the symposium. Pages 575-576 in C.J. Ralph and J.M. Scott (eds.). Estimating numbers of terrestrial birds. Studies in avian biol., No. 6. Allen Press, Lawrence, KS. 630 pp.

Erskine, A.J. 1978. The first ten years of the co-operative breeding bird survey in Canada. Can. Wildlife Service Rept. Ser. No. 42, Ottowa. 61 pp.

Feldhammer, G.A. 1977. Double captures of four rodent species in Oregon. Northwest Sci., 51:91-93.

Finley, R.B., Jr. 1980. Deficiencies and training needs in nongame wildlife management. Trans. N. Amer. Wildl. and Nat. Resources Conf. 45:268-270.

Flood, B.S., M.E. Sangster, R.D. Sparrowe, and T.S. Baskett. 1977. A handbook for habitat evaluation procedures. USDI, Fish and Wildlife Serv. Resource Publ. 132, Washington, D.C. 77 pp.

Franklin, J.F., R.E. Jenkins, and R.M. Romancier. 1972. Research natural areas: contributors to environmental quality programs. J. Environ. Quality 1:133-139.

Franzreb, K. 1977. Inventory Techniques for sampling avian populations. USDI, Bureau of Land Mgmt., Denver, CO. 17 pp.

Fuller, M.R., and J.A. Mosher. 1981. Methods of detecting and counting raptors: a review. Pages 235-246 in C.J. Ralph and J.M. Scott (eds). Estimating numbers of terrestrial birds. Studies in avian biol., No. 6. Allen Press, Lawrence KS. 630 pp.

Garton, E.O. 1981. Computerized analysis of census date. Pages 1-16 in F.L. Miller and A. Gunn (co-eds.). Symposium on census and inventory methods for populations and habitats. Contrib. No. 217, For., Wildl., and Range Exp. Sta., University of Idaho, Moscow. 220 pp.

Golly, F.B., K. Petrusewicz, and L. Ryszkowski (eds.). 1975. Small mammals: their productivity and population dynamics. Cambridge University Press, Cambridge. 451 pp.

Griffith, B., A.M. Wisht, W.S. Overton, and E.C. Meslow. 1981. Seasonal properties of the coyote scent station index. Pages 197-222 in F.L. Miller and A. Gunn (co-eds.). Symposium on census and inventory methods for population and habitats. Contrib. No. 217, For., Wild., and Range Exp. Sta., University of Idaho, Moscow. 220pp.

Halvorson, C.H. 1982. Rodent occurrence, habitat disturbance, and seedfall in a larch-fir forest. Ecology 63:423-433.

Hansson, L. 1967. Index lines as a basis of population studies on small mammals. Oikos 18:261-276.

Heatwole, H. 1982. A review of structuring in herpetofaunal assemblages. Pages 1-19 in N.J. Scott, Jr. (ed.). Herpetological communities. USDI Fish and Wildlife Service, Wildl. Res. Rpt. 13. Washington, D.C. 239 pp.

Hilborn, R., and C. Walters. 1981. Some pitfalls of environmental Baseline and process studies. Report number 3. Cooperative Fisheries Research Unit, Inst. of Animal Resource Ecology, The University of British Columbia, Vancouver, B.C. 8 pp.

Hinds, W.T. 1983. Food habits and monitoring strategies: Some lessons from field experience. Pages 153-156 in J.F. Bell and T. Atterbury (eds.). Renewable resources inventories for monitoring changes and trends. College of Forestry, Oregon State University, Corvallis. 737 pp.

Hirst, S.M. 1983. Ecological and institutional bases for long-term monitoring of fish and wildlife populations. Pages 175-178 in J.F. Bell and T. Atterbury (eds.). Renewable resources inventories for monitoring changes and trends. College of Forestry, Oregon State University, Corvallis. 737 pp.

Iker, S. 1984. A lifetime of listening. Bull. Ecol. Soc. Amer. 65:7-12.

Jannet, F.J., Jr. 1982. Nesting patterns of adult voles, Microtus montanus, in field populations. J. Mamm., 63:495-498.

Jenkins, R.E. 1977. Classification and inventory for the perpetuation of ecological diversity. Pages 41-52 in classification, inventory, and analysis of fish and wildlife habitat. FWS/OBS 78/76. USDI Fish and Wildlife Service, Washington, D.C. 604 pp.

Jenkins, S.H., and J.B. Llewellyn. 1981. Multiple captures of Peromyscus: Age, sex, and species differences. J. Mamm. 62:639-641.

Johnson, W.C., and B.L. Keller. 1983a. An examination of snap-trapping techniques for estimating rodent density in high desert. Northwest Sci. 57:194-204.

_____. 1983b. Examination of the area of effect of snap-trap transects in Idaho desert. Can. J. Zool. 61:403-410.

Jolly, G.M., and J.M. Dickson. 1983. The problem of unequal catchability in mark-recapture estimation of small mammal populations. Can. J. Zool. 61:922-927.

Keith, L.B. 1983. Role of food in hare population cycles. Oikos 40:385-395.

Kerr, R., and K. Brown. 1977. Data requirements for terrestrial wildlife habitat inventory. Pages 173-178 in classification, inventory, and analysis of the fish and wildlife habitat. FWS/OBS 78/76. U.S. Fish and Wildlife Service, Washington, D.C. 604 pp.

Kitchings, J.T., and D. J. Levy. 1981. Habitat patterns in a small mammal community. J. Mamm. 62:814-820.

Likens, G.E. 1983. A priority for ecological research. Bull. Ecol. Soc. Amer. 64:234-243.

Linn, I.J. 1963. A theory of small mammal index trapping. Proc. 16th Internat. Congr. Zool. 1:268. Washington, D.C.

_____, and F. Downton. 1975. The analysis of data obtained with small mammal index trapping. Acta Theriol. 20:319-331.

Lund, H.G. 1983. Change: Now you see it - now you don't! Pages 211-213 in J.F. Bell and T. Atterbury (eds.). Renewable resources inventories for monitoring changes and trends. College of Forestry, Oregon State University, Corvallis. 737 pp.

Mannan, R.S., and E.C. Meslow. 1981. Census techniques for nongame birds. Pages 181-196 in F.L. Miller and A. Gunn (eds.). Symposium on census and inventory methods for populations and habitats. Contrib. No. 217, For., Wild., and Range Exp. Sta., University of Idaho, Moscow. 220 pp.

Marcot, B.G., M.G. Raphael, and K.H. Berry. 1983. Monitoring wildlife habitat and validation of wildlife - habitat relationships models. Trans. N. Amer. Wildl. and Natur. Resources Conf. 48:315-329.

Martinka, R.R., and J.E. Swenson. 1981. A review of census techniques for North American upland game birds. Pages 158-180 in F.L. Miller and A. Gunn (eds.). Symposium on census and inventory methods for populations and habitats. Contrib. No. 217, For., Wildl., and Range Exp. Sta., University of Idaho, Moscow. 220 pp.

Maser, C.B., R. Mate, J.F. Franklin, and C.T. Durness. 1981. Natural history of Oregon coast mammals. USDA Forest Service Gen. Tech. Rept. PNW-133. Pac. NW For. and Range Exp. Sta., Portland, OR. 496 pp.

McDonald, L.L. 1981. Summarizing remarks: observer variablity. Pages 388-389 in C.J. Ralph and J.M. Scott (eds.). Estimating the numbers of terrestrial birds. Studies in avian biol. No. 6. Allen Press, Lawrence, KS. 630 pp.

Metzgar, L. 1971. Behavioral population regulation in the woodmouse, Peromyscus leucopus. Amer. Midl. Nat. 86:434-442.

Mihok, S. 1979. Behavioral structure and demography of subarctic Clethrionomys gapperi and Peromyscus maniculatus. Can. J. Zool. 57:1520-1535.

_____, and W.A. Fuller. 1981. Morphometric variation in Clethrionomys gapperi: Are all voles created equal? Can. J. Zool. 59:2275-2283.

Mikol, S.A. 1980. Field guidelines for using transects to sample nongame bird populations. USDI Fish and Wildlife Service. FWS/OBS 80/58. Washington, D.C. 26 pp.

Miller, F.L., and A. Gunn (Co-eds.). 1981. Symposium on census and inventory methods for populations and habitat. Contrib. No. 217, For., Wildl., and Range Exp. Sta., University of Idaho, Moscow. 220 pp.

Morrison, M.L. 1983. Assessing changes and trends in wildlife habitat in a forest management context. Pages 101-103 in J.F. Bell and T. Atterbury (eds.). Renewable resources inventories for monitoring changes and trends. College of Forestry, Oregon State University, Corvallis. 737 pp.

Mueggler, W.F. 1972. Plant development and yield on mountain grasslands in southwestern Montana. USDA Forest Service Res. Pap. INT-124 Intermt. For. and Range Exp. Sta., Ogden, UT. 20 pp.

O'Farrell, M.J., D.W. Kaufmann, and D.W. Lundahl. 1977. Use of live-trapping with the assessment line method for density estimation. J. Mamm. 58:575-582.

_____, and G.T. Austin. 1978. A comparison of different trapping configurations with the assessment line technique for density estimations. J. Mamm. 59:866-868.

O'Neil, L.J., and M. Schamberger. 1983. Habitat models as a monitoring tool. Pages 424-427 in J.F. Bell and T. Atterbury (eds.). Renewable resources inventories for monitoring changes and trends. College of Forestry, Oregon State University, Corvallis. 737 pp.

Paine, R.T. 1981. Truth in ecology. Bull. Ecol. Soc. Amer. 62(4):256-258.

Patric, E.F. 1958. Some properties of the small mammal populations of the Huntington wildlife forest. Unpubl. Ph.D. Thesis, Syracuse Univ., Syracuse, New York. 202 pp.

_____. 1970. Bait preference of small mammals. J. Mamm. 51:179-182.

Peterle, T.J., and R.H. Giles, Jr. 1964. New tracer techniques for evaluating the effects of an insecticide on the ecology of a forest fauna. RF Project 1207, Report 3. The Ohio State Univ. Research Foundation. Columbus. 435 pp.

Petticrew, B.G., and R.N.F.S. Sadleir. 1970. The use of index trap lines to estimate population numbers of deer mice (Peromyscus maniculatus) in a forest environment in British Columbia. Can. J. Zool. 48:385-389.

Pielou, E.C. 1981. The usefulness of ecological models: a stock-taking. The Quart. Rev. of Biol. 56:17-31.

Porter, W.F., N.E. Mathews, J. Doyle, and R.T. Brooks. 1983. The U.S. Forest Service Inventory: an approach for assessing wildlife habitat. Pages 623-631 in J.F. Bell and T. Atterbury (eds.). Renewable resources inventories for monitoring changes and trends. College of Forestry, Oregon State University, Corvallis. 737 pp.

Ralph, C.J., and J.M. Scott, eds. 1981. Estimating numbers of terrestrial birds. Studies in avian biol. No. 6. Allen Press, Inc., Lawrence, KS. 630 pp.

Raphael, M.G., and K.V. Rosenberg. 1983. An integrated approach to wildlife inventories in forested habitats. Pages 219-222 in J.F. Bell and T. Atterbury (eds.). Renewable resources inventories for monitoring changes and trends. College of Forestry, Oregon State University. Corvallis. 737 pp.

Reid, V.H., R.M. Hansen, and A.L. Ward. 1966. Counting mounds and earth plugs to census mountain pocket gophers. J. Wildl. Mgmt. 30:327-334.

Robbins, C.S. 1981. Birds activity levels related to weather. Pages 301-310 in C.J. Ralph and J.M. Scott (eds.). Estimating numbers of terrestrial birds. Studies in avian biol. No. 6. Allen Press, Lawrence, KS. 630 pp.

Romesburg, H.C. 1981. Wildlife Science: Gaining reliable knowledge. J. Wildl. Mgt. 45:293-313.

Salwasser, H., C.H. Hamilton, W.B. Krohn, J.L. Lipscomb, and C.H. Thomas. 1983. Monitoring wildlife and fish: mandates and their implications. Trans. N. Amer. Wildl. and Natur. Resources Conf. 48:297-307.

Schemnitz, S.D., ed. 1980. Wildlife management techniques manual. 4th Edition Rev. The Wildlife Society. Washington, D.C. 686 pp.

Schmidt, W.C., and J.E. Lotan. 1980. Phenology of common forest flora of the northern Rockies--1928 to 1937. USDA Forest Service Res. Pap. INT-259. Intermt. For. and Range Exp. Sta., Ogden, UT. 20 pp

Scott, N.J., Jr., ed. 1982. Herpetological communities. U.S.D.I., Fish and Wildlife Service. Wildl. Res. Rept. 13, Washington, D.C. 239 pp.

Sexton, O.J., J.F. Douglass, R.R. Bloye, and A. Pesce. 1982. Thirteen-fold change in population size of Peromyscus leucopus. Can. J. Zool. 60:2244-2225.

Short, H.L., and K.P. Burham. 1982. Technique for structuring wildlife guilds to evaluate impacts on wildlife communities. USDI, Fish and Wildlife Service. Spec. Scientific Rept. Wildl. No. 244. Washington, D.C. 34 pp.

Smith, M.H., R.H. Gardner, J.B. Gentry, D.W. Kaufman, and M.J.O'Farrell. 1975. Density estimations of small mammal populations. Pages 25-53 in F.B. Golley, K. Petrusewicz, and L. Ryszowski (eds.). Small mammals: their productivity and population dynamics. Cambridge Univ. Press, London. 451 pp.

Southern, H.N. 1965. The trapline index to small mammal populations. J. Zool. London. 147:217-221.

_____. 1973. A yardstick for measuring populations of small mammals. Mammal Review 3:1-10.

_____. 1979. The stability and instability of small mammal populations. Pages 103-133 in D.M. Stoddart (ed.). Ecology of small mammals. Chapman and Hall Ltd., London. 386 pp.

Stankey, G.H., P.J. Brown, and R.N. Clark. 1983. Monitoring and evaluating changes and trends in recreation opportunity supply. Pages 227-230 in J.F. Bell and T. Atterbury (eds.). Renewable resources inventories for monitoring changes and trends. College of Forestry, Oregon State University, Corvallis. 737 pp.

States, J.B., P.T. Haug, T.G. Shoemaker, L.W. Reed, and E.B. Reed. 1978. A systems approach to ecological baseline studies. U.S.D.I, Fish and Wildlife Service. FWS/OBS 78/21. Washington, D.C. 392 pp.

Sullivan, D.S., and T.P. Sullivan. 1980. Deer mouse trappability in relation to bait preference. Can. J. Zool. 58:2282-2284.

Terman, C.T. 1968. Population dynamics. Pages 412-450 in J.A. King (ed.). Biology of Peromyscus (Rodentia). Special publ. No. 2. The Amer. Soc. of Mammalogists. Lawrence, KS. 593 pp.

U.S.D.I., Fish and Wildlife Service. 1977. Classification, inventory, and analysis of fish and wildlife habitat. FWS/OBS 78/76. Washington, D.C. 604 pp.

Van Horne, B. 1981. Demography of Peromyscus maniculatus populations in seral stages of coastal coniferous forest in southeast Alaska. Can. J. Zool. 59:1045-1061.

Verner, J. 1983. An integrated system for monitoring wildlife on the Sierra National Forest. Trans. North Amer. Wildl. and Nat. Resources Conf. 48:355-366.

Vickery, W.L., and J.R. Bider. 1981. The influence of weather on rodent activity. J. Mamm. 62:140-145.

Vogt, R.C., and R.L. Hine. 1982. Evaluation of techniques for assessment of amphibians and reptile populations in Wisconsin. Pages 201-217 in N.J. Scott, Jr. (ed.). Herpetological communities. USDI, Fish and Wildlife Service, Wild. Res. Rep. 13. Washington, D.C. 239 pp.

Wagner, F.H. 1974. Models and the real world. Ecol. 55:1428-30.

Webster, A.B., and R.J. Brooks. 1981. Social behavior of Microtus pennsylvanicus in relation to seasonal changes in demography. J. Mamm. 62:738-751.

Wellner, C.A. 1972. Wildlife and wildlife habitat in ecosystem research. Annual meeting of West. Assoc. of State Fish and Game Commissioners, Portland, Oregon. 15 pp. Mimeo. Intermt. For. and Range Exp. Sta., Ogden, UT.

West, N.E. 1983. Choice of vegetation variables to monitor range condition and trend. Pages 636-639 in J.F. Bell and T. Atterbury (eds.). Renewable resources inventories for monitoring changes and trends. College of Forestry, Oregon State University, Corvallis. 737 pp.

West, S.D. 1982. Dynamics of colonization and abundance in central Alaskan populations of the northern red-backed vole, Clethrionomys rutilus. J. Mamm. 63:128-143.

Whiting, R.M., Jr., R.R. Fleet, and H.A. Pearson. 1983. Implementing and maintaining a system to monitor small mammal and bird populations. Pages 420-423 in J.F. Bell and T. Atterbury (eds.). Renewable resources inventories for monitoring changes and trends. College of Forestry, Oregon State University. Corvallis. 737 pp.

Williams, D.F., and S.E. Braun. 1983. Comparison of pitfall and conventional traps for sampling small mammal populations. J. Wildl. Mgmt. 47:841-845.

Wolk, E., and K. Wolk. 1982. Responses of small mammals to the forest management in the Bialowieza primeval forest. Acta Theriol. 3:45-59.

Woodwell, G.M. 1977. A confusion of paradigms (musing of a president-elect). Bull. of the Ecol. Soc. of America. 58:8-10.

Yang, K.C., C.J. Krebs, and B.L. Keller. 1970. Sequential live-trapping and snap-trapping studies of Microtus populations. J. Mamm. 51:517-526.

THE ECOLOGICAL PROFILE AS A MONITORING TOOL FOR LAKES IN YELLOWSTONE NATIONAL PARK

Robert E. Gresswell

ABSTRACT: Within Yellowstone National Park, over 150 lakes constitute 5 percent of the 899 000 ha. Since 1964, 112 lakes have been surveyed utilizing a holistic system consisting of basic physical, chemical, and biological parameters. The result, the Ecological Profile (EP), has allowed identification of unique features of each lake while providing data necessary for monitoring future changes and development of a general classification system. In conjunction with the Volunteer Angler Report, the EP has provided an economical means of evaluating human impacts of Park lakes.

INTRODUCTION

With a surface area of approximately 899 000 ha, Yellowstone National Park is one of the largest natural area preserves in the United States. Over 5 percent of the Park is covered by water, and lakes, lying at elevations between 1 680 m and 2 960 m, constitute approximately 43 000 ha. Four deep oligotrophic lakes, Yellowstone Lake, Shoshone Lake, Lewis Lake, and Heart Lake, account for 94 percent of the total lake surface area.

Although some information concerning the larger lakes was collected during the first half of the century, little was known about 130 smaller lakes scattered throughout the Park. In 1963, the National Park Service requested that the U.S. Fish and Wildlife Service fishery assistance office begin an inventory of lacustrine systems. Basic elements of the program included description of lake characteristics and acquisition of baseline data necessary for comparison through time.

Time and monetary constraints limited the program; consequently, a procedure that provided the information necessary for management purposes also had to be cost-effective. Initial efforts utilized standard lake survey techniques (Lagler 1956), and these studies emphasized the fishery potential of the various lacustrine waters. Methods changed somewhat between 1967 and 1972 with increasing effort on chemical parameters. Although fish sampling was originally conducted by experimental gillnet and hook and line methods, reliance on gillnetting alone increased precision and reduced the time spent on each lake, thereby reducing cost.

Robert E. Gresswell is a Fishery Biologist for the U.S. Fish and Wildlife Service, Yellowstone National Park, Wyo.

After reviewing procedures in 1973, it appeared that plankton, macroinvertebrate, and macrophyte sampling should receive greater emphasis. Beginning in 1974, commercial analysis of water samples substantially increased accuracy and the number of chemical parameters that were routinely evaluated while greatly reducing the time for field collection and analysis. This reduction more than compensated for extended time necessary for biological sampling. It also became apparent that more rigorous examination and synthesis of these data would provide greater insight into lacustrine dynamics.

The sampling and analytical system that ultimately evolved, the Ecological Profile (EP), is a holistic approach for examination of lakes in Yellowstone National Park. Through a system of qualitative and quantitative measurements, the EP focuses on the interaction between the watershed geology and vegetative cover, and the physical, chemical, and biological characteristics within each lake.

METHODS

A survey team of two individuals generally spends 2 days at each lake. A map of each lake, drawn to scale from 1:15840 aerial photos prior to field work, provides a basis for bathymetric studies and mapping of the surrounding basin.

Depth is measured along transects established at the time of the survey; the deepest spot in the lake is then utilized for pelagic sampling. Secchi disc visibility and temperature profile are measured at this station. Observations of lake color, turbidity, and wind exposure are recorded. Substrate type and variability are sampled at numerous points throughout the lake with an Ekman dredge.

Exploration of the immediate watershed provides additional physical information concerning riparian vegetation, erosion, angler trails, litter, and human modifications. Flow measurements are taken for all inlets and outlets, and descriptive data concerning permanency, gradient, pool-riffle ratio, substrate, productivity, and barriers to fish movement are noted. General characteristics of the watershed (topography, soil, cover) are also recorded.

During data analysis mean depth is estimated using the bathymetric map constructed from field measurements. Lake surface and drainage area are calculated from 15 minute series, USGS 1:62,500 topographic maps utilizing a dot-grid sheet. Together these data yield an estimate of total volume, and in conjunction with inlet and outlet flow, a flushing or exchange rate can be calculated. Lake maps also provide data for computing shoreline development. Geological description of the watershed is generated from USGS geological and surface geology maps of Yellowstone National Park.

A single midwater sample is collected from each lake at a depth of 2 m. A certified commercial laboratory furnishes chemical analyses for 38 different parameters in each sample including total dissolved solids (TDS), alkalinity, hardness, nitrogen, phosphorus, and major and minor ions. Measurements of conductivity, pH, and dissolved oxygen are taken in the field.

Numerous samples are taken for littoral and benthic macroinvertebrates, but plankton collection is limited to a single 9.1 m oblique tow. Preserved samples are returned to the laboratory for identification and quantification. The various locations of aquatic macrophytes are mapped, and samples are pressed for later identification.

One smallmesh (10-19 mm bar mesh) and two largemesh (19-51 mm bar mesh) experimental gillnets are generally set overnight. Measurements of length and weight are recorded for captured fish, and scales are collected for age and growth determinations. Cursory observations of stomach contents are also noted.

Ecological Profile (EP)

The EP is a synthesis of data that describes the major components of lake systems. Source materials that aid in interpretation include Hem (1970), Hutchinson (1967, 1975a, 1975b) Macan (1974), Moss (1980), and Wetzel (1975). The data base produced from all prior lake surveys provides additional information that enhances conceptualization. Understanding the interaction of chemical and physical parameters and the extent of their reflection in the biological community is essential to the EP. The presence or absence of various key organisms or types of organisms is used to indicate general sets of conditions. In conjunction with the identification of unique components of the system, these data help to evaluate changes through time. Assessment of the effects of human activities is utilized to predict the impact of future activities on various lake systems.

RESULTS AND DISCUSSION

A total of 112 Park lakes have been surveyed in the past 20 years. During this period, eight lakes have been visited twice, three lakes have received three visits, and one lake has been surveyed five times. The EP has enhanced the basic understanding of these waters, unique features have been identified and catalogued, and results have provided baseline data.

Evaluation of the structure and condition of the fishery is an important facet of the system; however, the presence or absence of fish is by no means an endpoint. In a designated natural area, such as Yellowstone Park, those waters that are historically fishless, or have reverted to a fishless condition, have a value equal to those that support a fish population. Fishless lakes, which commonly sustain distinctive lifeforms, offer a significant opportunity to appreciate rare communities as well as to investigate the effects of fish on community structure. Although there may be many hundreds of lakes in this country that can sustain fish life but lack reproductive habitat necessary to support a viable population, many of these currently support fisheries through frequent stocking. Because fish have not been planted to maintain wild trout fisheries in Yellowstone Park since 1954, the Park may encompass a significant proportion of this type of fishless lake in the country. The various forms of amphibians, macroinvertebrates, and plankton found only in fishless waters form a series of communities that are poorly documented.

The EP also provides excellent monitoring capabilities for lakes that do support fisheries. An independent, although integral system, the Volunteer Angler Report (VAR), provides annual statistics concerning angler use, harvest, and success for approximately 40 lakes in the Park. By utilizing the sizes of captured fish reported by the VAR with size and age structure data from experimental gillnets, the status of fish populations is assessed annually. This system allowed detection of severe declines of cutthroat trout in several Park lakes, and currently, monitoring studies are being conducted on four lakes to evaluate the effects of recent changes in angling regulations. Several populations of introduced species, including one that was later removed, have been identified during the EP evaluation.

By utilizing the holistic properties of the EP, all facets of a lake ecosystem can be compared to previous surveys in order to investigate possible causes for any observed trends. Preserved specimens of flora and fauna are indispensable for the detection of future change. Chemical data collected in conjunction with this program have also been utilized in an independent study concerning the susceptibility of waters in the Rocky Mountain area to acid precipitation.

In addition to baseline data acquisition and monitoring capabilities, the EP has been utilized as a foundation for a general classification system. Preliminary analysis of water chemical data indicated eight basic lake types within Yellowstone Park. Although continued analysis is necessary, it appears that sodium bicarbonate, calcium bicarbonate, calcium sulfate, sodium sulfate, sodium chloride, calcium chloride, magnesium bicarbonate, and dilute waters are types that appear to have distinctive biological characteristics. The relationship between water type and geological substrate of the watershed has also demonstrated lithological influences on the water chemistry of Park lakes.

Additional analyses have investigated the use of productivity indices such as the Trophic State Index (Carlson 1977) and the Morphoedaphic Index (Ryder 1965; Ryder and others 1974). It appears that these indices may have potential for classification of Park lakes, especially for those that support a fishery; however, substantial time and effort will be needed in order to fully integrate such indices into a comprehensive system that may also be useful outside Yellowstone Park. Future attempts at classification will also incorporate other characteristics of the EP including macrophytes, plankton, and macroinvertebrates in conjunction with additional physical limitations.

The EP has proved to be a valuable management tool in numerous ways. By identifying distinctive or unique species or ecosystems, it has an important deterministic feature. The system integrates known lake ecosystems with annual angler data so that human exploitation can be efficiently monitored. Future changes can potentially be explained because of baseline data acquisition, especially if replicate surveys are completed and reference collections are maintained. The EP has formed the basis for a classification system that will enhance the understanding and management of Yellowstone Park lacustrine systems and perhaps in the future, other systems in the Northern Rocky Mountains as well. Finally, as agency budgets continue to decline, the current cost of less than $1,000 per lake seems to be a reasonable cost to protect and preserve one of the most important natural area ecosystems remaining in the continental United States.

PUBLICATIONS CITED

Carlson, R. E. A trophic state index for lakes. Limnol. Oceanogr. 22(2): 361-369; 1977.

Hem, J. D. Study and interpretation of the chemical characteristics of natural water. 2nd ed. Geo. Surv. Water-Supply Pap. 1473. Washington, DC: U.S. Geological Survey; 1970. 363 p.

Hutchinson, G. E. A treatise on limnology, Volume 2. New York: J. Wiley and Sons; 1967. 1115 p.

Hutchinson, G. E. A treatise on limnology, Volume 1, Parts 1 and 2. New York: J. Wiley and Sons; 1975a. 1015 p.

Hutchinson, G. E. A treatise on limnology, Volume 3. New York: J. Wiley and Sons; 1975b. 660 p.

Lagler, K. F. Freshwater fishery biology. Dubuque, IA: W. M. C. Brown Co.; 1956. 421 p.

Macan, T. T. Freshwater ecology. 2nd ed. New York: Halstad Press; 1974. 343 p.

Moss, B. Ecology of freshwaters. New York: J. Wiley and Sons; 1980. 332 p.

Ryder, R. A. A method for estimating the potential fish production of north-temperate lakes. Trans. Am. Fish. Soc. 94(3): 214-218; 1965.

Ryder, R. A.; Kerr, S. R.; Loftus, K. H.; Reiger, H. A. The morphoedaphic index, a fish yield estimator - review and evaluation. J. Fish. Res. Board Can. 31(15): 665-688; 1974.

Wetzel, R. G. Limnology. Philadelphia, PA: W. B. Saunders Co.; 1975. 743 p.

INTEGRATED MONITORING IN MIXED FOREST BIOSPHERE RESERVES

G. B. Wiersma, C. I. Davidson, S. A. Mizell,
R. P. Breckenridge, R. E. Binda, L. C. Hull, and R. Herrmann

ABSTRACT: Sampling took place at Glacier National Park at two sites, an exposed and a remote site, in 1981 and 1982. Samples were analyzed for trace elements, sulfates, and nitrates. Media sampled included air, water, soil, vegetation, and forest litter. In general, atmospheric values measured reflect current literature estimates of background levels for these compounds. Moss samples and forest litter appeared to be enriched relative to crustal sources for such elements as lead, copper, and zinc. Two sites were instrumented for surface hydrology measurements. These efforts proved to be successful and demonstrated the feasibility of monitoring hydrologic limitations on very remote sites.

INTRODUCTION

This paper describes pollution monitoring that took place in Glacier National Park, Montana, a U.S. Biosphere Reserve. The biosphere reserve program is a component of the Man and Biosphere Program coordinated by the United Nations Educational, Scientific, and Cultural Organization (UNESCO). The biosphere reserve program is also coordinated with the United Nations Environment Program's Global Environmental Monitoring System (UNEP/GEMS). UNEP/GEMS has agreed to fund the establishment of a three-station pilot network for background monitoring. One of these sites will likely be in the United States, probably at Olympic National Park. The work discussed here has contributed to the development of the techniques and data bases necessary to conduct monitoring at global background stations.

METHODS

Some of the methods used in this study have been previously described (Wiersma and others 1979a; Wiersma and others 1979b; Wiersma and Brown 1981; and Brown 1981). Air sampling techniques were modified from previous studies and are described in detail by Davidson and others (1983).

The methodology for acid extraction of elements from soils is described below. After collecting the soils, they were transferred to No. 8 brown paper bags and dried for 24 hours at 40°C in a drying oven. After cooling to room temperature, the samples were sifted through a No. 20 (850 micrometer opening) standard testing sieve. Ten grams of the homogenized soil sample were then placed in 500-ml round-bottom flasks, to which 36 ml of concentrated nitric acid was added. Once foaming subsided, the mixture was refluxed for 18-20 hours. After digestion, the contents of the flasks were cooled, made up to 100 ml with the addition of deionized water, and filtered. Samples were then submitted for analyses. All analyses were performed in triplicate using an inductively coupled plasma emission spectrometer (ICP).

Plant and forest litter samples must be prepared prior to analysis by optical emission spectrometry (Alexander and McAnulty 1981). Preparation consisted of transferring samples to No. 8 brown paper bags and drying for 24 hours to 40°C in a drying oven. After cooling, the material was homogenized by use of a Spex Mizer/Mill. Plastic gloves were worn when transferring material to crushing vials, etc., to prevent contamination of samples.

SITE SELECTION

The objectives in selection of sites in Glacier National Park were to:

1. Determine the background levels for certain types of pollutants in Glacier National Park

2. Determine if there was a difference between a site close to human activity and a site that is more remote

To achieve these objectives, two sites were selected in the park. Site A, Martha's Basin, is shown in figure 1. Access to this site was only by trail. The site was 29 km from the trail head. No mechanized devices were used on the site, nor were any aircraft used to bring in supplies and equipment. Site B, Toad Valley, is also shown in figure 1. This was considered an exposed site and is located 3 km from Logan Pass visitor's center and Going-to-the-Sun Road. Both of these sites were chosen because they have similar aspects, vegetation types, drainage patterns, and altitude. A third site at Polebridge (fig. 1) was sampled for air concentrations only. This site was relatively close to a road.

At sites A and B, atmospheric concentrations were sampled for trace elements, sulfates, and nitrates. Dry deposition samples were collected. Stream chemistry samples were collected for trace elements, pH, conductivity, and total alkalinity. Selected vegetation samples, forest litter, and

---

G. B. Wiersma, Manager, EG&G Idaho, Inc.;
C. I. Davidson, Professor, Carnegie-Mellon University, 5000 Forbes Ave., Pittsburgh, Pa;
S. A. Mizell, Sr. Scientist, R. P. Breckenridge, Sr. Scientist; R. E. Binda, Assoc. Scientist;
L. C. Hull, Sr. Scientist, EG&G Idaho, Inc., P.O. Box 1625, Idaho Falls, Ida; and R. Herrmann, Director, Water Resources Field Support Laboratory, National Park Service, Colorado State University, Ft. Collins, Colo.

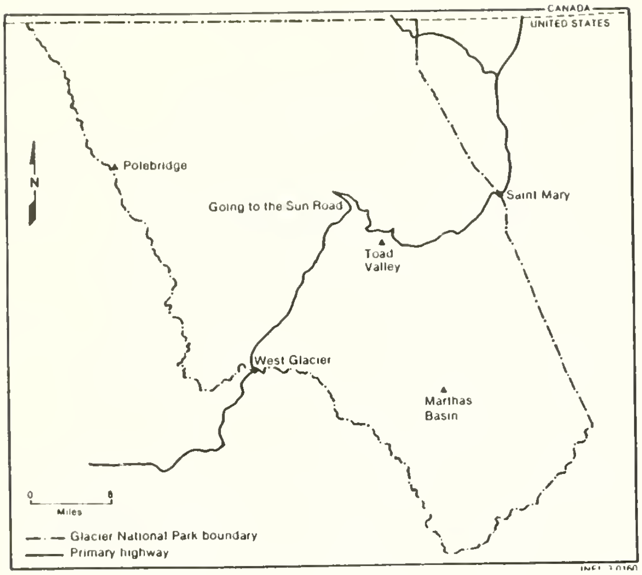


Figure 1.--Location of study sites in Glacier National Park, Site A - Martha's Basin (remote site); Site B - Toad Valley (exposed site)

soil samples were collected for trace element analysis. In addition, stilling wells and pigmy stream gauges were used to determine surface flow from each of these discrete watersheds. An automatic tipping bucket rain gauge was installed at site B to determine rainfall. This paper describes only the results for air, vegetation, litter, soil, and some of the results of the hydrology study.

Parallel sampling of vegetation was attempted in 1981 and 1982. However, Toad Valley could not be sampled in the fall of 1982 due to an early snow storm.

QUALITY ASSURANCE

An extensive quality assurance program was implemented. About 10 percent of all samples submitted were quality assurance samples. These samples were either known tomato leaf standards or replicated samples. For soil samples, a prepared standard solution was submitted along with the regular soil extracts. Quality assurance samples were submitted blind and at random to the analytical laboratories.

Table 1 is a summary of the quality assurance samples (NBS tomato leaf standard) submitted along with vegetation and litter samples. Approximately one sample and three replications went into each value in the table. Samples were analyzed by optical emission spectroscopy. In general, the results were acceptable. The criteria used were to accept the values presented if they were within ±25 percent of the NBS value or the upper and lower ranges of the NBS value. It should be pointed out that certified values for compounds such as aluminum, sodium, silica, etc., were not available. However, since the analytical procedure is a multielemental technique in which a single sample is analyzed for 26 elements at one time, one can probably draw the inference that if 14 of the 26 elements are good, then within reason the remaining elements have a certain degree of reliability.

Table 2 shows the quality assurance results for soil. Soil samples, as mentioned in the Methods section, were submitted as acid extracts. A standard solution with known values was submitted, along with our regular acid extract samples, acid blanks, and distilled water blank samples. All soil values reported have been corrected for these blank values. Based on the results, the soil values for barium, cobalt, silver, and strontium were rejected while the rest of the values were accepted. Because there may have been some problems with the quality control standard (the standard may have been kept too long), the acceptance criterion for trace elements in soil was broadened.

RESULTS - TRACE ELEMENTS

Table 3 shows the results for the air sampling for both Martha's Basin and Polebridge. The Toad Valley results are not reported because of the strong probability the samples were contaminated. For the most part, values for the Polebridge filters tended to be higher than those samples collected at Martha's Basin (remote site). This is true for both crustal elements and those that are suspected of having potential for enrichment.

Data for moss are shown in table 4. For the comparable data (Toad Valley vs. Martha's Basin for the summer of 1982), in the majority of cases for the elements listed, the values are higher at Toad Valley than they are in Martha's Basin. However, some values must be used with caution. For example, there appears to be a significantly larger amount of lead (333 µg/g vs. 124 µg/g) at Toad Valley than at Martha's Basin; but the quality assurance results for the same set of samples indicate unacceptably high lead values for the quality assurance samples from Toad Valley for moss.

In general, the results for moss between summer and fall 1982 appear to be very consistent. The exceptions are reduction by almost one-half for lead values and one-half for zinc values. Finally, Martha's Basin fall values from 1982 had higher lead, copper, iron, magnesium, and manganese levels than the fall values for 1981. A possible explanation for this is that Martha's Basin samples collected in 1981 were not actually in Martha's Basin. In 1982, the site was moved into Martha's Basin proper, a distance of about 3 air kilometers from the 1981 site.

Table 5 shows the results for other types of vegetation, primarily subalpine fir, Abies lasiocarpa, and woodrush, Luzula hitchcockii. In general, values for these forms of vegetation are lower than for moss for certain types of elements, for example, lead and copper.

Table 1.--Summary of quality assurance results from samples submitted with vegetation, moss, and litter collected in Glacier National Park (values in μg except where noted)

	Fall 1981					
	Martha's Basin			Toad Valley		
Element	Moss	Litter	Subalpine Fir	Litter	Subalpine Fir	Woodrush
B	34.6 ± 5	27.8 ± 6.9	33.6 ± 8.8	27.5 ± 5.7	28.6 ± 3.7	31.2 ± 6.6
Cd	2.8 ± 0.8	1.8 ± 0.1	3.6 ± 0.6	2.8 ± 0.8	2.4 ± 0.4	2.9 ± 1.8
Ca (%)	2.95 ± 0.3	3.53 ± 0.48	3.04 ± 0.24	2.88 ± 0.18	2.61 ± 0.24	2.97 ± 0.3
Cr	3.1 ± 0.1	3.6 ± 0.9	5.9 ± 0.4	4.3 ± 0.9	5.2 ± 0.7	4.9 ± 0.9
Co	0.8 ± 0.2	0.5 ± 0.1	0.6 ± 0.1	0.9 ± 0.2	0.8 ± 0.1	0.9 ± 0.2
Cu	11.0 ± 0.5	8.8 ± 1.2	11.0 ± 0.9	11.3 ± 0.5	11.9 ± 1.4	12.1 ± 1.3
Fe	674 ± 73	706 ± 98	656 ± 35	671 ± 12	715 ± 62	713 ± 57
Pb	7.0 ± 5.6	2.1 ± 3.8	6.1 ± 5.2	6.2 ± 6.1	-0.8 ± 1.9	1.9 ± 0.0
Mg	6800 ± 223	7200 ± 300	6660 ± 187	5700 ± 367	7420 ± 504	7230 ± 372
Mn	232 ± 28.7	228 ± 11	244 ± 18	245 ± 16	244 ± 25	235 ± 21
Sr	44.2 ± 2.5	48.5 ± 3.4	45.5 ± 3.2	43.2 ± 1.7	42.6 ± 2.7	45 ± 3.2
Zn	68.5 ± 7.0	83.2 ± 9.6	55.6 ± 0.9	73.2 ± 10.4	41.1 ± 8.2	50.3 ± 4.4
P	4370 ± 87	3920 ± 118	4620 ± 209	4070 ± 193	4030 ± 268	4070 ± 417
K (%)	4.13 ± 0.23	5.35 ± 0.69	4.78 ± 0.48	3.86 ± 0.22	4.37 ± 0.20	4.28 ± 0.10

	Summer 1982					
	Martha's Basin			Toad Valley		
Element	Moss	Litter	Subalpine Fir	Moss	Litter	Subalpine Fir
B	24.6 ± 1.3	27.8 ± 2.5	29.6 ± 4	26.0 ± 7	30.9 ± 1.6	28.6 ± 4
Cu	10.7 ± 0.2	10.8 ± .5	12.3 ± 1.8	10.6 ± .8	11.9 ± .9	10.1 ± .7
Fe	566 ± 96	524.9 ± 36	535 ± 90	400 ± 37	517 ± 46	394 ± 37
Pb	5.0 ± 4.0	ND	6.0 ± 5	15.8 ± 8	9.8 ± 8	18.8 ± 8.7
Mg	6698 ± 189	6303 ± 434	6541 ± 783	5447 ± 770	7074 ± 563	4834 ± 857
Mn	213 ± 8.8	273 ± 4	240 ± 10	214 ± 3	230 ± 45	212 ± 18
Sr	39.1 ± 3.1	36.9 ± 2.4	42.1 ± 5	39 ± 5.6	47.3 ± 4.7	38.4 ± 6.8
Zn	73.7 ± 5.4	18.8 ± 7.0	59.9 ± 19	49.2 ± 7.5	56.1 ± 7.6	66.2 ± 8.9

	Fall 1982			
	Martha's Basin			
Element	Moss	Litter	Subalpine Fir	Tomato Leaf Standard
B	26.8 ± .9	26.6 ± 1.6	24.1 ± .9	30.0
Ca (%)		2.9 ± .2	3.2 ± .3	3.00 ± 0.03
Cr		7.4 ± 5	5.1 ± .2	4.5 ± 0.5
Cu	13.9 ± .8	11.6 ± .7	14.1 ± .4	11.0 ± 1.0
Fe	589 ± 93	523 ± 33	521 ± 44	690 ± 25
Pb	6.9 ± 5	5.1 ± 2	3.0	6.3 ± 0.3
Mg	7282 ± 632	5704 ± 269	7546 ± 435	7000
Mn	236 ± 8	206 ± 3	252 ± 7.6	238 ± 7.0
Sr	48.5 ± 3	41.7 ± 3.5	45.4 ± 5.7	44.9 ± 0.3
Zn	46.3 ± 2.6	43 ± 2	58.3 ± 4.7	62 ± 6.0

Table 2.--Summary of quality assurance samples submitted with soil collected in Glacier National Park (µg/g)

Element	Martha's Basin - A Fall 1981	Toad Valley - B Fall 1981	Martha's Basin - A Fall 1982	Martha's Basin - A Summer 1982	Toad Valley Summer 1982	Toad QA Standard
Al	0.981	1.30	1.41	1.55	1.71	----
As	2.95	3.03	3.13	3.54	3.71	2.0
Ba	0.721	0.722	0.607	0.617	0.399	20.0
B	5.18	5.09	4.49	4.76	4.61	4.0
Cd	0.337	0.341	0.444	0.495	0.514	0.2
Ca	149	143	139	138	130	203
Cr	4.31	4.18	3.85	3.88	3.69	5.0
Co	1.62	1.82	4.64	6.24	6.93	0.3
Cu	1.67	1.67	1.53	1.58	1.59	2.0
Fe	1602	1537	1618	1594	1479	2000
Pb	1.86	1.77	2.28	2.31	3.63	2.0
Mg	166	158	134	134	128	201
Mn	46.7	45.2	39.3	39.5	37.9	50.0
Mo	0.277	0.353	0.411	0.532	0.615	----
Ni	8.41	8.25	7.62	7.85	7.72	10.0
Se	0.249	0.278	0	0	0	----
Ag	0.082	0.09	.162	0.204	0.173	2.0
Na	48.8	49.7	46.9	47.7	47.3	59.0
Sr	36.8	36.5	32.6	33.0	31.7	8.0
Sn	3.25	3.09	3.07	3.13	3.07	2.0
Ti	0.037	0.041	0.039	0.39	0.035	----
V	0.034	0.043	.074	0.92	0.105	----
Zn	8.24	7.88	6.78	6.85	6.62	10.0

Table 6 shows the results for trace elements in litter samples for 1981 and 1982 at both sites. In general, it appeared that in 1981 Martha's Basin had lower levels of trace elements than Toad Valley. This relationship did not appear again in the summer of 1982, and could be due to the site relocation in Martha's Basin. The 1982 summer values for the two sites appear to be similar. Sampling results from 1983, when available, should help clarify these levels.

Table 7 shows the results for soil analyses for both sites and for both years. Those elements that did not have good quality assurance have been eliminated. Basically, the two sites have similar trace element compositions.

Standard deviations have been calculated for all values. No statistics have been applied at this time. Therefore, final conclusions concerning real differences cannot be made. These analyses will be made in the final report that will include all the 1983 data.

RESULTS - HYDROLOGIC STUDY

Precipitation and stream discharge data were collected during the summers of 1981 and 1982. Also, attempts were made to instrument the groundwater systems; these efforts were terminated because the hand-powered drilling equipment used was incapable of penetrating overlying material. The hydrologic data were sought in order to quantify the water balance within the study areas. Table 8 summarizes the type of information obtained.

The two field areas instrumented during this study are very similar in character. However, there are some differences which include: (1) the bedrock geology--Toad Valley is in limestone and Martha's Basin is in argillite, (2) the drainage area above the stream stage recorder--Toad Valley is 1.6 km^2 and Martha's Basin is 11 km^2, and (3) Toad Valley exposure is ENE--Martha's Basin is E.

A tipping bucket, recording rain gauge was temporarily installed at the Toad Valley site during the 1982 field season. No precipitation data were collected for Martha's Basin. Stream-stage recorders were placed in both areas during each season.

Two activities are included in the stage/discharge data acquisition. The first involved continuous monitoring and recording of changes in stream stage at the study sites. The second activity required periodic gauging of stream velocity at a specific stage level. These two activities provided data necessary to determine stream discharge variations through time and to estimate the total volume of water passing the recorder station as surface flow.

DISCUSSION - HYDROLOGIC STUDY

Stage hydrographs from Toad Valley show some response to local, concurrent rainfall events.

Table 3.--Preliminary airborne concentrations from Glacier National Park-1981 (ng/m^3 STP except where noted)

	Martha's Basin	Polebridge
CRUSTAL ELEMENTS		
Al	82	240
Ba	8.2	13
Ca	240	320
Fe	120	130
Mg	43	240
Mn	28	39
Na	650	150
ENRICHED ELEMENTS		
Ag	<0.16	.085
As	1.6	2.5
Cd	0.98	0.45
Cu	----	<6.9
Pb	4.6	4.6
Zn	----	9.0
Sulfate	0.73 μg/m^3 1.48 μg/m^3	
Nitrate	>1.36 μg/m^3 0.71 μg/m^3	

This relationship is illustrated by comparison of 1982 precipitation and stream flow records for August 30 and 31, and September 4 and 5 (figs. 2 and 3). Additional features of the Toad Valley hydrographs that may imply response to local rainfall include the sharp rise and fall of the 1981 record (fig. 4) and the steep drop in water level following the August 15, 1982, precipitation event (fig. 3). Long-lasting periods of high flow do not appear to be an immediate response to local precipitation events. These high flows may result from antecedent snowmelt or precipitation conditions, or unrecorded precipitation events

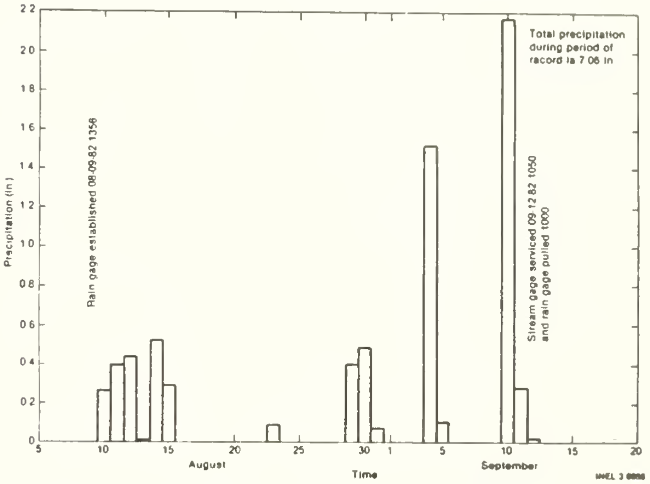


Figure 2.--Daily precipitation "Toad Valley" Glacier National Park, August 9 to September 13, 1982

Table 4.--Average concentrations of selected elements in moss from Glacier National Park (values on a dry weight basis - in μg/g except where noted)

Elements	Martha's Basin - A Fall 1981	Martha's Basin Fall 1982	Toad Valley Summer 1982	Martha's Basin Summer 1982
Al	1817	1840	2377	1915
Ba	236	229.5	166.6	213.4
B	6.07	11.4	17.4	12.5
Cd	0.825	ND	ND	ND
Ca	8852	7078	3159	5559
Cu	7.31	32.7	35.8	33.5
Fe	1093	4245	5187	4238
Pb	26.7	61.7	332.8	124.4
Mg	2196	4203	5129.5	4521.3
Mn	537	1186	944.4	1572
Ti	192	614	1025	772.6
V	3.7	13.0	36.6	20.3
Zn	67.5	23.5	29.4	47.0
Na	510	4096	8364	5084
Sr	86.2	43.3	29.22	37.9

Table 5.--Average concentrations of selected trace elements in vegetation collected from Glacier National Park (values in µg/g except where noted)

Element	Martha's Basin - A Fall 1981 Abies lasiocarpa	Toad Valley - B Fall 1981 Abies lasiocarpa	Toad Valley - B Fall 1981 Luzula hitchcockii	Toad Valley Summer 1982 Abies lasiocarpa	Martha's Basin Summer 1982 Abies lasiocarps	Martha's Basin Fall 1982 Abies lasiocarpa
Al	472	401	975	255.9	236.4	176.0
Ba	107	76.3	69.5	81.9	93.5	81.8
B	20.3	14.0	8.9	14.8	19.4	16.0
Cd	6.6	6.4	2.9	ND	ND	ND
Ca	1328	6262	4702	4770	4564	3959
Cu	2.57	1.99	2.56	4.6	5.3	6.2
Fe	182	140	728	112.8	87.5	70.1
Pb	5.69	30.4	15.68	4.1	4.6	4.55
Mg	1456	1253	1642	652.7	1062.4	966.0
Mn	839	434	515	529.2	560.4	366.1
Na	231	1207	281			
Sr	55.7	7.3	10.8	5.11	5.9	4.74
Ti	8.0	3.26	106	9.97	8.6	4.83
V	1.2	1.7	2.7	2.8	2.5	
Zn	40.1	45.0	209	40.2	47.2	47.3

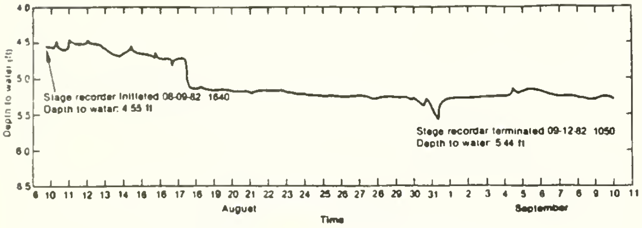


Figure 3.--Stream stage at "Toad Valley" recorder, Glacier National Park, August 9 to September 10, 1982

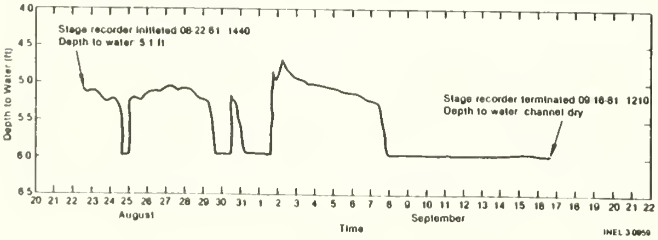


Figure 4.--Stream stage at "Toad Valley" recorder, Glacier National Park, August 22 to September 16, 1981

(1981 record). The long duration events may reflect temporary storage of water in surface depressions or in soils.

The 1982 hydrograph from Martha's Basin (fig. 5) exhibited an entirely different character from those obtained in Toad Valley. The slow, steady decline in stage shown by the Martha's Basin hydrograph seemed little influenced by concurrent rainfall, probably because of the large drainage area and the lakes present in the basin. Another

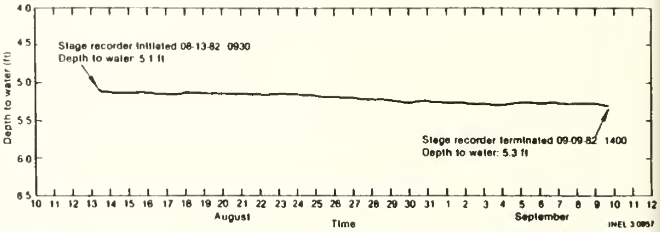


Figure 5.--Stream stage at Martha's Basin recorder on Coal Creek, Glacier National Park, August 13 to September 9, 1982

factor that may contribute to the hydrograph differences was the geology at each site. Toad Valley's fractured limestone probably allowed extensive underflow; Martha's Basin argillite (rock derived from clay or silt) allowed little or no underflow.

An initial estimate of the importance of various factors of the water balance equation can be obtained by comparing the volume of water entering the drainage area to that discharged. Concurrent precipitation and discharge data exist only for Toad Valley during the period August 9 through September 9, 1982. During this period, 11.7 cm of rain was recorded at the gauge. Under the assumption of uniform distribution of rain throughout the drainage area above the stage recorder, this rainfall was equivalent to 1.8×10^5 m^3. Thus, surface drainage accounted for 94 percent of the water entering the drainage area. This implied that very little water was stored in the drainage area and that the importance of other parameters in the water balance (i.e., evaporation, transpiration, infiltration) was small. These observations must be tempered by recognizing that this exercise was based on only 1 month of data and likely did not represent

Table 6.--Average concentration of selected elements in litter from Glacier National Park (values on a dry weight basis in μg/g except where noted)

Element	Martha's Basin - A Fall 1981	Toad Valley - B Fall 1981	Martha's Basin - A Summer 1982	Toad Valley Summer 1982	Martha's Basin Fall 1982
Al	3158	5267	1537.0	1949.9	1475
Ba	330.2	253.1	190.5	167.3	182.7
B	10.22	19.29	10.84	16.6	11.6
Cd	6.11	5.58	ND	ND	ND
Ca	11456	6182	5667	6217	6994
Cu	21.83	56.32	20.36	27.6	24.5
Fe	2449	4615	3102.2	4030.6	3288
Pb	156.9	275.6	52.7	54.4	37.2
Mg	2088	7246	1778.1	4011	2495.3
Mn	1572	738	1795	1146	1324.5
Na	1754	3541	1308	2953	1854
Sr	96.08	36.3	30.0	25.2	28.6
Ti	460.7	1102	411	691	414.8
V	6.44	11.13	11.6	21.8	11.9
Zn	95.97	81.86	28.3	41.8	32.1

Table 7.--Average concentration of selected elements in soil from Glacier National Park Biosphere Reserve (values on a dry weight basis - μg/g)

Element	Martha's Basin - A Fall 1981	Toad Valley -B Fall 1981	Martha's Basin - A Summer 1982	Toad Valley - B Summer 1982	Martha's Basin - A Fall 1982
Al	8829	18390	13080	14249	12935
B	4.17	8.92	21.07	18.29	18.4
Cd	0.884	----	1.57	2.16	1.25
Ca	391	2249	1319	1331	1155
Cr	5.88	10.21	8.35	8.53	8.28
Cu	9.61	10.26	5.77	6.86	5.94
Fe	9902	16700	8592	11068	8951
Pb	9.08	25.7	8.69	9.0	7.83
Mg	1781.7	6418	6550	4334	6853
Mn	402	841	654.8	51.47	447
Mo	0.96	----	1.14	2.07	0.15
Na	106	66.9	109.4	136.96	90.92
Ti	260	509	186.3	291.05	172
V	16.4	30.0	15.82	20.31	39.27
Zn	21.94	84.75	39.41	47.4	39.6

Net Values = Reported Value - (acid and water blank values)

Table 8.--Summary of hydrologic data available from Glacier National Park activities

Field Site	Period of Record[1]	Precipitation	Stream Stage	Stage/Discharge
Toad Valley	1981-1982	Yes[2]	Yes	Yes[3]
Martha's Basin (Site 1)	1981	No	Yes (?)	Yes[4]
Martha's Basin (Site 2)	1982	No	Yes	Yes[3]

[1]The hydrologic field seasons were: August 19 to September 16, 1981, and August 9 to September 12, 1982. The short field seasons are dictated by the long winters in Glacier National Park.

[2]The 1982 field season is currently the only period of continuous precipitation record.

[3]Three stage/discharge values are available.

[4]One stage/discharge value is available.

conditions existing during other portions of the year.

The above discussion of hydrologic data gathered in Glacier National Park is based solely on information collected during the limited field seasons of that region. Analysis of these data can be made more complete and quantitative if additional information is obtained to:

1. Define the meteorological character of the region, especially regarding the type of precipitation events that occur during the summer

2. Extend the precipitation record by comparison with data from a local or regional, full-time recording station

3. Estimate the annual contribution of water from snowmelt.

DISCUSSION - POLLUTANT DATA

The air data from Glacier National Park (table 3) show some of the lowest trace element values recorded on the continental United States. Davidson and others (1983) reported values for lead in Olympic National Park of 2.2 ng/m^3. Fox and Ludwick (1976) reported atmospheric lead values at Quillayute, Washington, ranging from 2.3 ng/m^3 to 32 ng/m^3. The lower value represented air masses arriving at Quillayute after transit for several days over the northern Pacific Ocean. Davidson and others (1980) reported lead values of 0.9 ng/m^3 for Hotel Everest View in Nepal, cadmium values less than 0.04 ng/m^3, and silver values less than 0.05 ng/m^3. Zoller and others (1974) reported lead values at the South Pole of 0.63 ng/m^3, and copper of 36 ng/m^3. The above information supports the assertion that the Glacier National Park atmospheric trace element values are probably representative of global background values for the same elements.

Sulfate values from Martha's Basin were from two successive sampling periods. Their average is 1.1 µg/m^3. This is probably what one could expect from a relatively clean site. Alkezweeny and others (1982) reported sulfate values over the Seney National Wildlife Refuge in Northern Michigan of 0.7 µg/m^3 to 1.2 µg/m^3. Barnes and Eggleton (1977) reported sulfate values for Pendeen, England, when wind was from maritime sources, of 1.9 µg/m^3 and less. Therefore, the sulfate levels found in Martha's Basin are representative of relatively clean air masses. Similar conclusions can be drawn about nitrate values measured in the park.

Three types of vegetation were collected. Results for subalpine fir and woodrush are shown in table 5 and for moss in table 4. Normally, trace element values in vascular plants are rather variable. However, moss tends to give fairly reliable trace element results. The major reason for this was postulated by Tyler (1972). He indicated that an ion exchange occurred on the surface of moss plants. Therefore, airborne trace elements landing on them tended to absorb into the plant rather than adsorb to the plant surfaces.

One technique of helping to determine probable sources of trace elements in the atmosphere is through the use of enrichment factors. Normally, enrichment factors are used for calculating relative quantity of a trace element in the atmosphere in relationship to some average crustal values (Rahn 1976). However, the technique can be used to compare other media and has been applied to moss and litter results. Local soils can be used, but for consistent results, the soils should have undergone complete digestion. Soil results in this paper are acid extractions and, therefore, Taylor crustal values were used for comparison (Taylor 1964). The enrichment factor is calculated according to the following formula:

$$EF = \frac{C_x / C_{Al}}{C_{x\,source} / C_{Al\,source}}$$

Where C_x is the concentration of any element in the medium of concern, C_{Al} is the concentration of aluminum in the compared medium; $C_{x_{source}}$ is the the concentration of the element of concern in the potential source medium; and $C_{Al_{source}}$ is the concentration of aluminum in the same medium.

Moss concentrations for a series of trace elements were compared to Taylor crustal values. These trace elements are not known to have long-term transport characteristics. In other words, they are not normally enriched in air relative to crustal sources. Table 9 shows that for crustal elements, all have enrichment factors less than 10 with the exception of manganese; 10 is considered an approximate breaking point between being enriched (>10) and not being enriched (<10) (Duce and others 1975; and Alkezweeny and others 1982). This implies that, in general, the moss plants have ratios of these elements about equal to what one would expect if there were crustal sources for these elements. Similar results obtained when moss is compared to air indicate that a good deal of the measured concentration of elements in moss merely comes from resuspended local crustal materials.

Basin ranged from 19.4 for copper to 250 for lead. In Toad Valley they ranged from 14.1 for zinc to 933 for lead. In both locations, lead had by far the highest enrichment factor and Toad Valley lead enrichment factor was over three times greater than Martha's Basin. However, QA results show that the lead values for Toad Valley may be unrealistically higher. Therefore, the difference between sites may not be as large as it appears.

When moss is compared to air for the elements considered to be enriched in the atmosphere, virtually no enrichment was found. In this case, one can hypothesize that the lead, zinc, and copper had as a possible source the atmosphere, and the enrichment of these elements in moss resulted from the deposition of airborne particles and eventual absorption into the plant. These elements were also enriched in the atmosphere (Davidson and others 1983) in Glacier National Park. This indicates sources were not crustal in origin. A strong probability exists they were anthropogenic in origin. The exception is cadmium. Cadmium at Martha's Basin is definitely highly enriched over crustal values. However, the atmosphere seems to be about 33 times more enriched in cadmium than moss. Explanation for this is not apparent at this time.

Table 9.--Enrichment factors for moss using Taylor crustal values for comparison in soil and measured atmospheric values for comparison in air*

	Martha's Basin		Toad Valley	
	Moss/Soil	Moss/Air	Moss/Soil	Moss/Air
CRUSTAL				
Magnesium	6.9	3.4	7.6	2.2
Manganese	51.1	1.5	34.5	2.4
Calcium	7.6	1.2	2.6	1.0
Iron	2.5	0.3	3.2	4.0
Sodium	8.4	0.3	12.3	4.8
Titanium	4.0	No air data	6.2	No air data
ENRICHED				
Cadmium	165.0	0.03	None detected in moss	None detected in moss
Copper	19.4	None detected in air	22.7	None detected in air
Lead	250.0	0.6	933	7.3
Zinc	29.0	None detected in air	14.1	0.3

*Because of difficulties with Toad Valley air data, data from PoleBridge, another exposed site in the Park, were used.

This relationship holds for both Martha's Basin and Toad Valley. However, the situation changes for those elements generally considered in the literature to be enriched in the atmosphere. Enrichment factors were calculated for these elements in moss compared to Taylor crustal values (table 9). Here enrichment factors in Martha's

Litter is an important part of a forest ecosystem. It is an active site for trace metal accumulation and eventual movement into the mineral soil (VanHook and others 1977); it is also intimately associated with soil. Table 10 shows that, in general, elements in litter considered to be crustal had no enrichment over what would be

Table 10.--Enrichment factors for litter using Taylor crustal values for comparison in soil and measured atmospheric values for comparison in air*

	Martha's Basin		Toad Valley	
	Litter/Soil	Litter/Air	Litter/Soil	Litter/Air
CRUSTAL				
Magnesium	3.6	1.8	5.5	1.6
Manganese	65.8	1.9	23.7	4.7
Calcium	7.7	1.3	3.4	1.3
Iron	2.1	0.3	1.7	2.2
Sodium	2.8	0.1	3.1	1.4
Titanium	3.0	No air data	3.6	No air data
ENRICHED ELEMENTS				
Cadmium	1218	0.22	617	0.8
Zinc	31.2	None detected in air	21.2	0.4
Lead	263.0	0.6	305	2.4
Copper	14.9	None detected in air	17.3	0.4

*Because of difficulties with Toad Valley air data, data from PoleBridge, another exposed site in the Park were used.

expected when compared to Taylor values. The exception, as in moss, was manganese. Also, no enrichment was found when compared to air values. Again, one can hypothesize that the litter is reflecting entrapment by vegetation of resuspended locally derived material. It also reflects some direct mixing of mineral soil material with organic material.

Elements considered to be enriched in the atmosphere are also enriched in litter at both sites when compared to Taylor crustal values. Lead again is more enriched at Toad Valley. Cadmium shows much greater enrichment for Martha's Basin than in Toad Valley. This was demonstrated by Davidson and others (1983) for air samples collected at Martha's Basin. These had an enrichment factor for cadmium of 5400 compared to 790 for cadmium at the Polebridge site.

When litter values were compared to air values, no enrichment was noted. Again, one can hypothesize that the primary source of the enriched elements in litter is from atmospheric deposition of wet, dry, and atmospheric particles intercepted by trees and eventually washed off or dropped with dead organic material onto the forest floor.

CONCLUSIONS

Trace element levels and sulfate and nitrate values in the atmosphere of Glacier National Park, in general, reflected current literature estimates or background levels for these compounds. However, moss and litter samples from both sites were enriched when compared to earth crustal values for lead, cadmium, copper, and zinc. The source of these elements in both moss and litter was postulated to be atmospheric deposition.

Obvious differences between the exposed and remote sites are not apparent. Judgment on the relative exposure of the two sites will have to wait until 1983 data are analyzed and detailed statistical analyses can be performed.

Finally, it was shown that remote sites (up to 30 km from road) can be instrumented for hydrological studies and maintained. All this information will aid in setting up a true background monitoring site at Olympic National Park, a designated U.S. Biosphere Reserve.

PUBLICATIONS CITED

Alexander, G. V.; McAnulty, L. T. Multielement analysis of plant-related tissues and fluids by optical emission spectrometry. Journal of Plant Nutrition 3(1-4): 51-59; 1981.

Alkezweeny, A. J.; Laulainen, N. S.; Thorp, J. M. Physical, chemical and optical characteristics of a clean air moss over Northern Michigan. Atmospheric Environment 16(10): 2421-2430; 1982.

Barnes, R. A.; Eggleton, A. E. J. The transport of atmospheric pollutants across the North Sea and English Channel. Atmospheric Environment 11: 879-892; 1977.

Brown, K. W. Pollutant monitoring in the Olympic National Park Biosphere Reserve. Environmental Monitoring and Assessment 1(1): 37-48; 1981.

Davidson, C. I.; Grimm, T. C.; Nasta, N. A. Concentrations of lead and other trace elements in the air and snow of the Himalayas. Dept. of Civil Engineering and Engineering and Public Policy. Carnegie-Mellon University, Pittsburgh, PA 15213; 1980.

Davidson, C. I.; Wiersma, G. B.; Brown, K. W.; Gould, W. D.; Mathison, T. P.; Reilly, M. T. Airborne trace elements in Great Smoky Mountains, Olympic and Glacier National Parks. Submitted to Environmental Science and Technology; 1983.

Duce, R. A.; Hoffman, G. L.; Zoller, W. H. Atmospheric trace metals at remote northern and southern hemisphere sites: pollution or natural? Science 187: 59-61; 1975.

Fox, T. D.; Ludwick, J. D. Lead (Pb) Concentrations associated with 1000 mb geostrophic back trajectories at Quillayute, Washington. Atmospheric Environment 10: 799-803; 1976.

Rahn, K. A. The chemical composition of the atmospheric aerosol. Technical Report Graduate School of Oceanography, University of Rhode Island, Kingston, RI; 1976.

Taylor, S. R. Abundance of chemical elements in the continental crust: a new table. Geochemica Et Cosmochimeca Act. 28: 1273-1285; 1964.

Tyler, G. Heavy metals pollute nature, may reduce productivity. Ambio 1(2): 52-59; 1972.

VanHook, R. I.; Harris, W. F.; Henderson, G. S. Cadmium, lead and zinc distributions and cycling in a mixed deciduous forest. Ambio 6(5): 281-286; 1977.

Wiersma, G. B.; Brown, K. W.; Herrmann, R.; Taylor, C.; Pope, J. Great Smoky Mountains preliminary study for biosphere reserve pollutant monitoring. EPA-600/4-79-072. U.S. Environmental Protection Agency, Las Vegas, Nevada; 1979a.

Wiersma, G. B.; Brown, K. W. Recommended pollutant monitoring system for biosphere reserves. In: Successional Research and Environmental Pollutant Monitoring Associated with Biosphere Reserves. Proceedings Second US/USSR Symposium on Biosphere Reserves. March 10-15, 1980. Everglades National Park, Florida, USA. M. A. Hemstrom and J. F. Franklin, eds.; 1981.

Wiersma, G. B.; Frank, C. W.; Brown, K. W.; Davidson, C. I. (in press). Lead particles in the Great Smoky Mountains Biosphere Reserve. U.S. Environmental Protection Agency, Las Vegas, Nevada; 1979b.

Zoller, W. H.; Gladney, E. S.; Duce, R. A. Atmospheric concentrations and sources of trace metals at the South Pole. Science 183: 198-200; 1974.

COST-EFFICIENT BASELINE INVENTORIES

OF RESEARCH NATURAL AREAS

Edward O. Garton

ABSTRACT: A cost-efficient approach to baseline inventories of research natural areas has been forced on us by the scarcity of funding for such surveys. Such an approach requires the use of cost-efficient survey methods and application of a particular strategy. The elements of this strategy must include a systematic team approach, a careful definition of objectives, and a continuous effort to simplify all aspects of the work.

INTRODUCTION

Research natural areas (RNA) in the Northern Rocky Mountains represent a valuable source for knowledge of the functioning and dynamics of natural populations, communities, and ecosystems There is a real need for inventories of these areas so that they can be used for basic research, for comparison to managed areas, and for long-term studies of stasis and change. But how is this to be accomplished in the face of declining funds for research in the natural resource fields? One solution is to wait for more funds to become available. Another is to begin the work without delay by applying the most cost-efficient methods available. This paper is an attempt to suggest a strategy for this approach and some conclusions from applying it to the Bannock Creek Research Natural Area in the Boise Basin Experimental Forest, Idaho.

A COST-EFFICIENT STRATEGY

Conducting a cost-efficient survey depends as much upon a proper strategy as upon particular methods. The elements of this strategy must include a systematic team approach, a careful definition of objectives, a continuous effort to simplify and the use of cost-efficient survey methods. These elements must be combined with all the other characteristics of objective scientific research for a baseline survey to be successful.

A systematic approach is essential in cost-efficient surveys because limited funding makes errors or omissions disastrous. Scientists with the International Biological Programme (IBP) made an initial effort to systematize basic inventory efforts by developing a check sheet to be completed for all present and potential IBP natural areas (Peterken 1967; Clapham 1980). Ohlman (1973) utilized the IBP check sheets and added a checklist of steps for gathering vegetation data in temperate forest research natural areas. The checklist in table 1 should help in developing a systematic procedure for inventorying all the components of research natural areas.

Baseline inventories, by definition, must gather basic information for all components of the natural ecosystems surveyed, including characteristics of the topography, soil, geology, climate, weather, hydrology, terrestrial and aquatic vegetation, and terrestrial and aquatic fauna. This will not be possible unless a team approach is taken, relying upon experts in the various fields. Although most or all of the field work must be performed by technicians to reduce costs, the design, planning, analysis, and evaluation must be done by a team of experts.

The most critical element of a cost-efficient strategy for inventorying research natural areas involves carefully defining the objectives of the inventory. The objectives for each research natural area must be defined individually based upon the significance of that particular area both locally and regionally. Does this forested RNA contain relatively undisturbed stands that would be ideal to compare to the surrounding intensively harvested forest? Does this area include habitats, species, or features that are unique within the region? What is most important about this area? To reach a final definition of objectives, we must weigh the significance of specific components against the value of characterizing all of the components in some detail and reach some workable and justifiable compromise. This will only be successful if we force ourselves to simplify and to be realistic as to what can be accomplished with the available resources of people and funds.

Once the objectives have been defined, methods can be chosen to obtain the information necessary to meet those objectives. The most efficient methods that just meet the objectives must be chosen. In general, these will be extensive rather than intensive methods. They will measure physical, structural, or time-specific characteristics of the components rather than rates or dynamic characteristics. Only when particular species or communities are of particular

Edward O. Garton is Associate Professor of Wildlife Resources, University of Idaho, Moscow.

Table 1.--A checklist of steps for inventorying research natural areas

- __ 1. Obtain establishment report for the RNA.
- __ 2. Gather USGS topographic maps, aerial photos, soil maps, geological maps, vegetation maps, etc.
- __ 3. Contact agency, university, and private personnel to obtain all available information on characteristics of the RNA, its prior history, and studies carried out there.
- __ 4. Carry out a preliminary classification of the RNA into vegetation types.
- __ 5. Identify features of particular significance.
- __ 6. Make a preliminary definition of objectives of the inventory.
- __ 7. Request necessary permits and permissions.
- __ 8. Conduct a preliminary reconnaissance of the RNA, accompanied by local people with most knowledge of the area, if possible.
- __ 9. Revise objectives of the inventory and send them out for review.
- __ 10. Summarize characteristics of the RNA from all information gathered under each category below:
  - __ a. Topography
  - __ b. Soil
  - __ c. Geology
  - __ d. Weather and climate
  - __ e. Hydrology
  - __ f. Terrestrial vegetation
  - __ g. Terrestrial fauna
  - __ h. Aquatic flora
  - __ i. Aquatic fauna
- __ 11. Map homogeneous units (vegetation types, stream sections, etc.) identifiable on aerial photos for use as survey strata.
- __ 12. Finalize objectives.
- __ 13. Verify that all necessary permits and permissions are obtained.
- __ 14. Design data gathering procedures to meet objectives for each component.
  - __ a. Select methods.
  - __ b. Design data forms and code book.
  - __ c. Plan data analysis in detail.
  - __ d. Consult with an applied statistician.
- __ 15. Conduct preliminary survey to do the following:
  - __ a. Revise map of strata based on ground reconnaissance.
  - __ b. Gather sample data for each method where it is not already available.
- __ 16. Complete study design.
  - __ a. Analyze preliminary sample data to estimate variances.
  - __ b. Determine sample sizes, work-hours, costs, etc.
  - __ c. Revise design as necessary, deleting objectives, reallocating effort and funds.
  - __ d. Consult with an applied statistician.
- __ 17. Conduct field work.
  - __ a. Insure quality control.
  - __ b. Revise methods if necessary.
- __ 18. Analyze data.

Table 1.--Cont.

- __ 19. Write up results of inventory and distribute as appropriate.
- __ 20. Write up recommendations for further work and for follow up.
- __ 21. Deposit all specimens in museum and herbarium collections.
- __ 22. Deposit all data, reports, descriptions of field procedures, forms, code books, and methods of data analysis in two different repositores (one local and one regional).

significance will intensive methods be justified for those components at the expense of detail in other components.

INVENTORY APPROACH

Cost-efficient baseline inventories must take an approach quite different from intensive ecosystem studies such as the biome programs of the IBP or the intensive studies of particular components typically conducted on experimental forests or grasslands. Certain aspects of this approach, as outlined in the checklist (table 1), need to be emphasized. It is essential to gather every shred of information already available before gathering any yourself. This is the cheapest way to obtain information and for some components it may be all that can be obtained in a cost-efficient survey. As information accumulates repeatedly revise the objectives and delete those that are not feasible. Do not accept any information obtained uncritically. Evaluate and validate it where possible. Get all the free help possible from specialists and pay for it where necessary. This may be more cost-efficient than trying to obtain the information with untrained assistants. Do not overlook the necessity of obtaining permits and permissions. Obtain information from studies on similar areas and/or conduct a pilot survey of all field methods to obtain sample data on variation in characteristics, cost and work-hour requirements of methods. Finally, consult an applied statistician during the design phase and just prior to conducting the field work.

INVENTORY METHODS

There are generally a wide array of methods available to gather information on any particular component of a natural ecosystem. The methods differ in their level of detail, bias, precision, and time/cost requirement. At one extreme are broad scale, reconnaissance, index methods that produce information lacking in detail and precision, often with large potential for bias. Cost-efficient surveys must utilize methods closer to this end than to the other extreme of methods

applied to individual species, requiring large numbers of replications and repeated samples through time, and often entailing costly laboratory analyses of samples. The methods can be grouped and rated on their applicability to cost-efficient surveys on the basis of the characteristics that they measure (table 2).

Table 2.--Cost-efficiency rating of methods available to inventory characteristics of research natural areas

Characteristic	Cost-Efficiency Rating[1]
Topography	
Contour map	1
Elevation (range and median)	1
Profile graphs	1
Classification of drainage patterns	1
Landform map	2
Numerical description of drainage networks	
Stream orders	2
Stream density (number/area)	2
Drainage density (length/area)	2
Channel and lake basin descriptions	
Stream gradient	2
Channel cross-sections (width, depth, shore water depth, pool characteristics)	4
Pool-riffle ratio	4
Basin cross-sections (width, depth, volume)	4
Soils	
Soil map	
Reconnaissance map of general patterns of soil occurrence	1
Detailed survey map of individual soil units	4
Site map of all variations on local site	5
Soil profile of sample points	
Field description of horizons, thickness, color, and gross structure	1
Lab tests of particle size distribution, structure, bulk density, specific gravity, and porosity	4
Moisture characteristics (moisture content, infiltration rates, field capacity, and avaliable moisture capacity)	4
Soil temperature profile	4
Geology	
Large-scale geologic characteristics of the region	1
Reconnaissance survey of surface and exposed subsurface characteristics	3
Detailed subsurface survey	5

Table 2.--Cont.

Characteristic	Cost-Efficiency Rating[1]
Climate, weather, and hydrology	
Large-scale climatic characteristics (mean min. and mean max. monthly temperatures, mean precipitation, frost-free period)	1
Incident solar radiation	4
Atmospheric conditions	
Air temperature (minimum, maximum)	3
Humidity	4
Barometric pressure	4
Windspeed and direction	4
Cloud cover	4
Airborne particle content	3
Gaseous content (especially pollutants)	3
Hydrologic characteristics	
Evaporation and transpiration rates	4
Precipitation (rain and snowfall, snow depth and condition, pH)	3
Runoff and channel flow	4
Water conditions (temperature, light penetration, turbidity, color, pH, alkalinity, hardness, conductivity, dissolved oxygen)	3
Terrestrial vegetation	
Vegetation maps	
PI (photo interpretation) units	1
Cover types based on brief reconnaissance	1
Habitat types based on ground reconnaissance	3
Habitat type-seral stages based on ground reconnaissance	4
Structural characteristics	
Forest trees	
Frequency	1
Basal area	2
Crown closure	2
Stand table (density/basal area in dbh classes)	2
Height distribution	2
Stock table (volume in dbh classes)	4
Leaf area index	4
Shrubs, tree saplings, herbaceous vegetation, grasses, and seedlings of woody plants	
Frequency	1
Density	2
Cover	2
Biomass	4
Dynamic characteristics	
Accretion (growth in size of individuals)	4
Regeneration	4
Phenology	5
Colonization	5
Morbidity	5
Mortality	4

Table 2.--Cont.

Characteristic	Cost-Efficiency Rating[1]
Terrestrial vegetation (cont.)	
Dynamic characteristics (cont.)	
Removal by consumption and harvest	5
Net production	5
Woody debris	
Biomass of litter and duff (if not sampled in soil survey)	2
Size distribution and biomass of larger material	3
Rates of accumulation and decay	4
Terrestrial fauna	
Taxonomic groups	
Small birds	2
Small mammals	2
Reptiles and amphibians	3
Upland birds	3
Arthropods	3
Furbearers	3
Raptors	3
Large mammals	3
Large carnivores and bears	5
Population and individual characteristics	
Presence (species list)	1
Relative abundance (site to site)	2
Home range size	3
Diet	3
Density	3
Sex ratio	4
Age structure	4
Survival	5
Fecundity	5
Immigration	5
Emigration	5
Aquatic flora	
Forms that may be sampled as a group	
Planktonic forms	2
Submerged vegetation	3
Floating vegetation	3
Emergent vegetation	4
Characteristics	
Presence (species list)	2
Relative abundance (site to site)	3
Absolute abundance (biomass)	4
Phenology	5
Losses	5
Production	5
Aquatic fauna	
Forms that may be censused as a group	
Planktonic forms	2
Macroinvertebrates	2
Amphibians	3
Fish	3
Aquatic mammals	4
Aquatic birds	3

Table 2.--Cont.

Characteristic	Cost-Efficiency Rating[1]
Aquatic fauna (cont.)	
Characteristics	
Presence (species list)	1
Relative abundance (site to site)	2
Diet	4
Density	4
Sex and age structure	4
Survival	5
Fecundity	5
Immigration	5
Emigration	5

[1]Cost efficiency rating:
- 1=Very cost efficient; should be done in general.
- 2=Moderately cost efficient; generally will be done.
- 3=Fairly cost efficient; may be done.
- 4=Expensive; should be done rarely.
- 5=Extremely expensive and time consuming; almost never feasible.

Topography

Most of the topographic information that is feasible to gather for a RNA will come from USGS topographic maps (7½ min series) and widely available aerial photographs at scales of 1:12,000 to 1:24,000. A contour map is readily drawn from a USGS topographic map using a pantograph, mapograph, or similar device. This can serve as a base map for all other maps. The elevation range and profile graphs can also be produced from USGS topographic maps. Aerial photos can be used to classify drainage patterns, draw a land form map and obtain the simpler numeric information describing drainage networks and lake basins (table 2).

Soil

Reconnaissance maps of the general patterns of soil occurrence have been drawn by the USDA Soil Conservation Service (SCS) for most areas of the U.S. with agricultural potential. It will rarely be possible to gather more information on the distribution of soil types than is contained in the maps and reports prepared by the SCS. If such maps are not available for the area including the RNA, a decision will have to be made whether their value justifies the cost of preparing them for the RNA. Detailed soil descriptions should be made at each site where terrestrial vegetation is sampled, however. These descriptions will generally need to be restricted to field descriptions of the soil profile sampled with an auger.

Geology

Extremely high costs preclude anything more than a gross characterization of the geology of RNAs.

Climate, Weather, and Hydrology

Weather and hydrologic conditions at any site must be sampled repeatedly through time because of their nature and daily and yearly cycles. It will not often be possible to obtain more information than what is available from the National Weather Bureau or published studies. In occasional cases where atmospheric or hydrologic conditions are of particular significance, it may be possible to sample air temperatures, air pollutants, precipitation, or water conditions in particular seasons (see table 2 for details).

Terrestrial Vegetation

Mapping vegetation patterns within a RNA is an essential first step in designing a sampling scheme for both plant and animal communities. Mapping photo interpretation (PI) units is possible from moderate scale aerial photography. Fairly detailed PI units can be identified on large scale (about 1:4000) photos and may justify their expense if the RNA is within short flight time of an airport where a commercial aerial photographer operates. Photos at this scale provide a valuable record of the distribution of larger plant species and plant communities. A brief ground reconnaissance can provide sufficient information to convert this PI unit map into a cover type map. If a habitat type classification system is available for the area, and resources allow, it would be preferable to conduct a more thorough ground reconnaissance and map habitat types.

The vegetation types mapped will form the strata from which to select sample points to characterize the vegetation quantitatively. If only one or two samples can be drawn, then these should be located subjectively by picking areas to sample that are most representative of the vegetation type. However, it is much better to draw a number of randomly located samples from each stratum. There are a large variety of approaches available for sampling vegetation (Mueller-Dombois and Ellenberg 1974), but I recommend using nested permanent plots. Permanent plots are desirable so that plots can be remeasured later to begin studying dynamic aspects of the vegetation. Nested plots of varying size are needed to sample the different vegetation strata (trees, shrubs, grasses, forbs, and seedlings of woody species). On the Bannock Creek RNA, K. Pregitzer used a system consisting of a 0.1 hectare circular plot in which all living and standing dead trees greater than 10 cm dbh were tagged, heights estimated with clinometer, and diameters measured, a concentric 375 m^2 plot in which plant canopy coverage was estimated for all vascular plants, a concentric 50 m^2 plot in which tree regeneration less than 10 cm dbh was counted, and 28 microplots (0.5 m x 0.5 m) in which plant coverage and shrub basal diameters and heights were recorded (Garton and others 1983). Downed woody material was surveyed using Brown's (1982) procedures. Measurements at a number of permanent plots like these in each vegetation type provide estimates of the structural characteristics, frequency, basal area, dbh distribution, height distribution and cover for trees and frequency, density and cover for shrubs, tree saplings, herbs, grasses, and seedlings of woody plants. It will rarely be feasible to gather more that this in cost-efficient inventories. Estimates of dynamic characteristics (table 2) will require resurveying these permanent plots at a later time. Photographic records of each plot could be very useful during followup surveys and require little expenditure in time and funds. It should be noted that no attempt to measure below-ground characteristics of the vegetation seems feasible in cost-efficient surveys.

Terrestrial Fauna

Sampling all of the taxonomic groups of terrestrial animals is not possible on an RNA larger than a few hectares. The first decision must be which groups to survey. The decision should be based upon the importance of information for each group from this RNA and the ease with which the information can be obtained. Small territorial birds and small mammals are the two groups most efficiently sampled during the early summer breeding season. Reptiles, amphibians, upland birds and select groups of arthropods (defoliating lepidoptera, ground beetles, etc.) may sometimes be sampled. Furbearers, raptors, large mammals, large carnivores, and other arthropods will be too costly to census in general.

Obtaining information on the presence, relative abundance, and density of the selected animal groups is generally feasible on a limited budget, but more detailed information (table 2) is not. On Bannock Creek RNA, I found transect methods (Emlen 1971; 1977) to be 50 percent more efficient than variable circular plots (Reynolds and others 1980) for estimating density of small birds. We were able to sample small birds in four stands and small mammals in one stand during this survey (Garton and others 1983). Relative indices of abundance for all other animal groups are more efficient than absolute density estimates (Caughley 1977). Estimates of other characteristics of terrestrial animals (table 2) can only be undertaken for individual species of special importance such as rare species. Caughley (1977), Davis (1982), Schemnitz (1980) and Seber (1983) describe these methods. Such work will probably preclude censusing any other terrestrial animals in cost-efficient inventories, but may be justified in some cases.

Aquatic Flora

Studies of aquatic flora are time consuming and costly and can only be undertaken if the aquatic resources are of particular significance on the RNA. Such work will rarely be able to provide more information than a species list and estimates of relative abundance at reasonable cost (table 2).

Aquatic Fauna

Aquatic fauna must be treated in a manner similar to terrestrial fauna. Macroinvertebrates, micro-invertebrates, and fish are the groups most easily sampled (table 2). Estimates of relative abundance are the most detailed characteristics that are feasible to obtain in cost-efficient inventories. Platts and others (1983) provide a guide to sampling methods for aquatic communities. F. Rabe surveyed the invertebrates on the main trunk of Bannock Creek, a third order stream, with seven permanent stations at which debris dam, pool, and riffle habitats were sampled (Garton and others 1983)

COST

Cost-efficient, baseline inventories of research natural areas are feasible as long as it is recognized that they cannot provide a comprehensive and complete inventory of the characteristics of the area. Cost efficient inventories of research natural areas the size of Bannock Creek RNA (about 200 hectares in area) should not be undertaken for less than $15,000. This level of funding was allocated as follows in the Bannock Creek RNA Study: $4,000 to sample terrestrial vegetation, $5,000 to sample aquatic invertebrates, $5,000 to sample small birds and mammals, and $1,000 to coordinate the project and prepare study plans and reports. It would have required about $30,000 to sample the structural characteristics of the components in a comprehensive manner, and substantially more than that to estimate dynamic characteristics of even a few components. Taking the approach outlined here, it will probably take $10,000 to $15,000 per 100 hectares to conduct a cost-efficient inventory of a typical RNA.

PUBLICATIONS CITED

Brown, J. K.; Oberheu, R. D.; Johnston, C. M. Handbook for inventorying surface fuels and biomass in the Interior West. U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; Gen. Tech. Rep. INT-129; 1982.

Caughley, G. Analysis of vertebrate populations. London: John Wiley and Sons; 1977. 234 p.

Clapham, A. R. The IBP survey of conservation sites: an experimental study. Cambridge: Cambridge University Press; 1980. 344 p.

Davis, D. E. (ed.). CRC handbook of census methods for terrestrial vertebrates. Boca Raton, FL: CRC Press, Inc.; 1982. 397 p.

Emlen, J. T. Population densities of birds derived from transect counts. Auk 88:323-342; 1971.

Emlen, J. T. Estimating breeding season bird densities from transect counts. Auk 94:455-468; 1977.

Garton, E. O.; Pregitzer, K.; Rabe, F. W. Baseline inventory of the terrestrial and aquatic resources of the Bannock Creek Research Natural Area. Final Report to Intermountain Forest and Range Experiment Station, June 1983. Moscow, ID: Forest, Wildlife and Range Experiment Station, University of Idaho; 1983. 150 p.

Mueller-Dombois, D.; Ellenberg, H. Aims and methods of vegetation ecology. New York, NY: John Wiley and Sons; 1974. 547 p.

Ohlman, L. F. Vegetation data collection in temperate forest research natural areas. St. Paul, MN: U.S. Department of Agriculture, North Central Forest Experiment Station; Res. Pap. NC-92; 1973. 35 p.

Peterken, G. F. Guide to the check sheet for IBP areas. Int. Biol. Program Handbook 4. Oxford, Edinburgh: Blackwell Scientific Publishers; 1967. 133 p.

Platts, W. S.; Megahan, W. F.; Minshall, G. W. Methods for evaluating stream, riparian, and biotic conditions. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; Gen. Tech. Rep. INT-138; 1983. 70 p.

Reynolds, R. T.; Scott, J. M.; Nussbaum, R. A. A variable circular-plot method for estimating bird numbers. Condor 82:309-313; 1980.

Schemnitz, S. D. (ed.). Wildlife management techniques manual. Fourth ed. Washington, DC: The Wildlife Society; 1980. 686 p.

Seber, G. A. F. The estimation of animal abundance and related parameters. Second ed. London: Charles Griffin and Co.; 1983. 654 p.

SOME STATISTICAL ASPECTS OF BASELINE MONITORING IN RESEARCH NATURAL AREAS

Gordon D. Booth

ABSTRACT: Two main topics on baseline monitoring are discussed. First, the CUSUM chart is introduced as a means of detecting departures from the norm. And second, the periodogram is introduced as a means of detecting cyclical patterns in research natural areas (RNA) data.

INTRODUCTION

Many aspects of baseline monitoring in research natural areas (RNA's) are statistical. The statistical procedures described here, though not presently used in baseline monitoring of RNA's, have definite potential.

An important aspect of any monitoring program is, or course, the establishment of a baseline. In many cases, it is not easy to define this line for a specific study. Without a clear definition of what constitutes the baseline, it is impossible to know when conditions have departed from it--either within the same research natural area or in some other area for which the RNA was to serve as a control.

Some statistical methods appear well-adapted to application in monitoring research natural areas. For example, techniques common in acceptance sampling could be applied easily to RNA monitoring.

Because monitoring is based on repeated measurements taken over time, we are really observing what statisticians call a time series. Some of the procedures used in the study of such series of measurements have the potential of yielding unique, useful information. For example, what are the magnitudes of seasonal variations in the variables being measured? Are there other nonseasonal cycles? If so, how frequently do they occur? How strong are they? Answers to these questions can lead to an understanding of the underlying physical relationships and can guide the researcher to seek explanations that otherwise would not have been sought.

Paper presented at the Symposium on Research Natural Areas: Baseline Monitoring & Management, Missoula, Mont. March 21-24, 1984. Gordon D. Booth is a Mathematical Statistician with the Intermountain Forest and Range Experiment Station, Forest Service, USDA, Ogden, Utah.

THE CUSUM CHART

Often the purpose of monitoring the baseline is to help us (1) determine whether some characteristic of the RNA has changed, or (2) whether a characteristic of some other area has changed. Both objectives require criteria for judging when a real change has taken place.

Industrial quality control is that branch of industry that deals with the quality of the finished product. Several statistical techniques help assure that products of poor quality are not released. Some of these techniques involve repeated sampling of a production process, taken at different times. This type of quality control is called acceptance sampling, and several of its methods can be modified for application to the monitoring of an RNA.

One of the methods used in acceptance sampling is the Cumulative Sum Chart, or CUSUM chart. The procedure involves repeated sampling at intervals over time. Each sampled result is used to plot a point on a special chart. If the plotted values show a pattern that indicates a change in the underlying system, the monitoring method declares the system "out of control." In the case of a research natural area, we could monitor levels of pollutants, species diversity, soil conditions, or any of many other characteristics of interest.

The CUSUM chart is a simple graph of the cumulative departures from a target value. The target can be selected by the investigator or it may be mandated by law. The principle of the CUSUM chart is based on the fact that, if we keep adding departures from the target value, the positive and negative deviations will cancel one another. Therefore, the cumulative sum will hover near zero. This is true if the system being monitored is centered on the target value. On the other hand, if a real change takes place in the system, the cumulative sum will steadily depart from the zero line--either above or below.

The CUSUM chart is easy to use and effective. To illustrate its use, data from Hall and others (1980) will be studied. The data represent calcium concentrations measured for 32 weeks. The measurements were made at a fixed site on a stream. After the measurement was made for week 6, acid was added 120 m upstream from the measurement site. These data are plotted in figure 1.

The acid spill simulates a precipitation event of high acid concentration that enters the stream through runoff. From figure 1, we see an upward trend in the data. This would indicate an increase in calcium concentration.

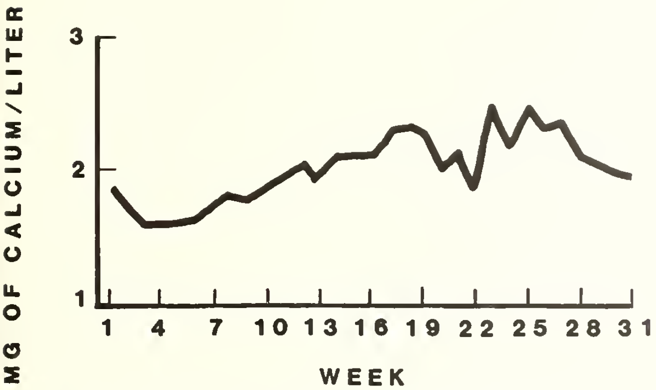


Figure 1.--Calcium measured downstream from the site of an acid spill that occurred after the measurement was taken for week 6. Units are milligrams of calcium per liter.

However, if we were monitoring the calcium baseline in the stream, our interest might be in detecting the change in concentration as early as possible. We would not have the advantage of hindsight as illustrated in figure 1. At what week would we be willing to conclude that a real increase in calcium concentration had taken place? And if so, when did it occur? If we had data only up to and including week 13, would we feel comfortable claiming an increase in calcium concentration had taken place? Probably not.

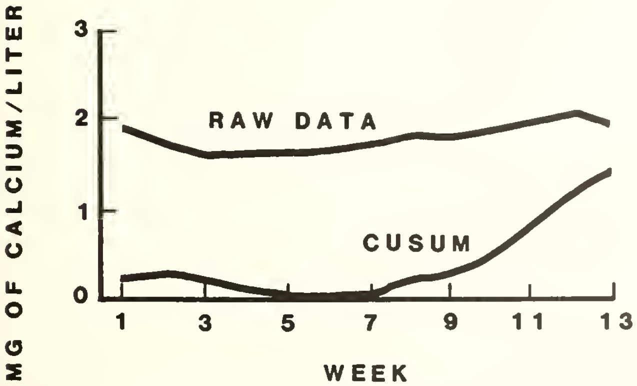


Figure 2.--Comparison of information available from raw data and from a CUSUM chart of the calcium concentration data from Hall and others (1980).

Figure 2 allows us to compare the monitoring information contained in the raw data with that contained in the CUSUM chart for the first 13 weeks. During this period it would be difficult to detect any real trend in the raw data. Nevertheless, if we had been monitoring with the CUSUM chart, we would have suspected a change as early as week 10 and would have been even more convinced by week 11. By week 13 we would have been almost certain, and furthermore, we would suspect that the change took place at about week 7.

This example illustrates the basic characteristics of the CUSUM chart. First, it is particularly sensitive to departures from a reference value. Second, it is possible to tell at approximately what point in time the change took place. And third, early detection is possible. The thing to look for in a CUSUM chart is a change in slope. Obviously, such a change took place at about week 7. Even as late as week 13, the effect of the acid spill was not at all evident in the raw data.

CUSUM charts have many facets to their use and construction. There are methods (Grant and Leavenworth 1980; Duncan 1974) available for determining when the CUSUM chart indicates a real change in the baseline.

The CUSUM chart provides one of the most straightforward methods of monitoring a baseline, and it should find wide application in research natural areas. The same method could also be used in long-term monitoring with less frequent measurements. However, the continuously decreasing cost of automated data collection devices may make more frequent sampling in RNA's a common occurrence.

CYCLICAL PATTERNS

Data obtained from monitoring should almost always be plotted against time to reveal important information. For example, on a graph, time trends become apparent and seasonal cycles are usually clearly visible. However, other important cycles often are not visible at all. Nevertheless, these other cycles can provide us with invaluable information concerning underlying phenomena. For instance, the presence of hidden cycles can greatly influence observed values in a monitoring system. The failure to take such cycles into account could cause us to attribute normal cyclical behavior to some other not-real source.

The Search for Cycles

The methods of searching for periodic (that is, cyclical) behavior in data fall into the general heading of Fourier analysis, or as it is sometimes called, harmonic analysis. This is a set of techniques for describing data in terms of periodic components. When certain cyclical patterns are found to exist, in addition to the expected seasonal ones, it should encourage the researcher to investigate potential underlying causes. Without knowledge that nonseasonal cycles exist, underlying causes would never be sought. Many of the data obtained through monitoring programs lend themselves to Fourier analysis.

The Periodogram

One of the main tools in the search for cycles is the periodogram, a chart showing frequencies and how strongly they are represented in the data. These frequencies refer to the number of times a cycle occurs during the time the sample was taken. For example, if we sampled for 90 days, a frequency of 2 would refer to a cycle that occurred twice during the 90 days. A frequency of 3 would mean the cycle repeated three times during our sampling period.

A cycle is represented on a graph as a peak followed by a valley. Therefore, a cycle repeated many times would have evenly spaced peaks. The time from the crest of one peak to that of the next peak is called the "period" of the cycle. A bar chart that emphasizes the presence of cycles with different frequencies or periods is called a periodogram. If the bar that corresponds to a given frequency is high, a cycle of that frequency is present in the data. There are methods available for determining how high the bar must be to have confidence that the cycle is real.

The power of the periodogram comes from its ability to untangle the component cycles, when several cycles are superimposed. In such cases, visual inspection of a graph often fails to reveal the true periodic components.

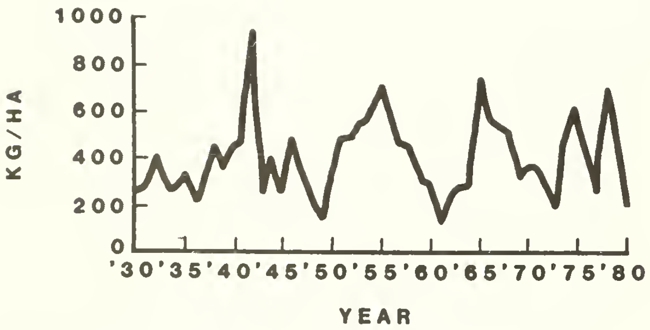


Figure 3.--Herbage yield data from Hanson and others (1982). Units are kilograms per hectare.

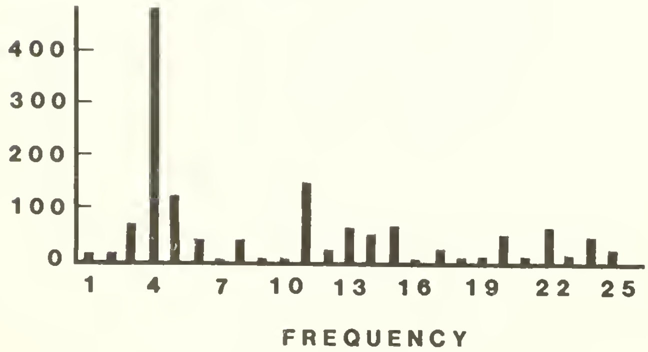


Figure 4.--Periodogram of herbage yield data from Hanson and others (1982).

Hanson and others (1982) discuss herbage yield over 51 years. The raw data are shown in figure 3. The authors did not discuss the cyclical aspects, but some cycles are evident in the periodogram of their data (fig. 4).

Although some form of periodicity is obvious in the raw data, the exact nature of the cyclical components cannot be seen easily. From the periodogram, there is an obviously influential cycle with a frequency of about 4. This means the cycle repeats four times during the 51 years sampled. To obtain the period of the cycle we simply divide the frequency into the number of years sampled. This gives a period of 51/4 = 12.75 years. Therefore, there is a strong cyclical component in the data that repeats about every 12 to 13 years. Another periodic component in the data appears at a frequency of about 11, which corresponds to a period of about 4.6 years. This second component is weaker, and may not be real. Nevertheless, the data are suggestive of a cyclical pattern occurring about every 4 to 5 years.

It would be reasonable for the investigators to seek possible explanations for both the 12- to 13-year and the 4- to 5-year cycles. Because herbage yield can be dramatically affected by available moisture, it might be worthwhile determining whether cycles of similar periodicity are present in precipitation data.

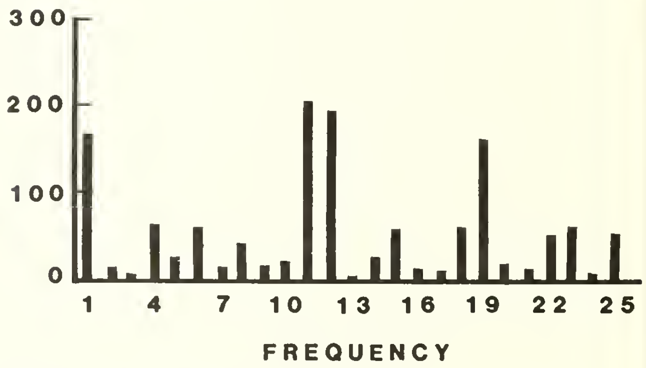


Figure 5.--Periodogram of precipitation data from Finklin (1983). Units are inches.

Finklin (1983), for instance, presents precipitation data for the same time span, but for an area several hundred miles away. The periodogram for the precipitation data is presented in figure 5. We do not find a precipitation cycle with a period of 12 to 13 years (that is, a frequency of about 4), but we do find one of 4 to 5 years (corresponding to a frequency of about 11). Should we attribute the 4- to 5-year herbage yield cycle to precipitation? While we do not propose to answer that question here, the basic tools for suggesting questions and answers are

available in the periodogram. Interestingly, cycles of about 11 years are common in precipitation data, although none was found in this case. It should also be noted that for a meaningful study, we should have considered precipitation data from the same geographical area as the herbage data. Unfortunately, such data were not readily available.

The theory of the periodogram includes confidence intervals and tests. It provides us with a method of discovering cyclical behavior of the characteristic being monitored. Failure to recognize such cycles and to make allowance for them can lead to false conclusions. For instance, if an increase is observed in the characteristic being measured, we need to know that it is not a regularly occurring cyclical pattern. Otherwise, the increase in the monitored value could cause unwarranted management action.

Frequency of Measurement

In the study of any time series such as the monitoring of a research natural area, a key question is, How often should measurements be taken? The full answer is too extensive for inclusion here. However, several basic concepts will be discussed.

If monitoring takes place on a yearly basis, any cycles with periods shorter than 1 year will, obviously, be missed. For example, if measurements were made each May it would be impossible to study seasonal patterns. There would be no data available at any time of year other than May. If we want to study patterns with periods shorter than 1 year, we should sample several times each year and at the same times each year. For instance, if we want to study seasonal patterns we should take monthly, weekly, or daily readings rather than annual ones. It would be inappropriate to sample in February in some years and in March in others, because it could lead to an inaccuracy that could easily mask all but the strongest patterns in the data. Sampling should be made at equally spaced intervals of time.

Another basic concept is that of an alias frequency. Due to the rate at which samples are taken (that is, the sampling rate), some frequencies are indistinguishable from others, thus are aliases of one another. If a value is monitored at short intervals, it is more likely that important frequencies will be detected free of their aliases. However, frequent sampling is more costly. Bloomfield (1976) discusses aliases in detail.

Intervention Analysis

While the periodogram emphasized the frequency of cycles in the data, another approach emphasizes the ability to predict future values based on historical patterns. The emphasis is on the variable time and how measurement errors at one instant are related to those at other times. Attempts are made to measure the relationship of errors at one time to those errors that precede it. The methodology is described best by Box and Jenkins (1976), and was developed by them over several years.

One application of the Box-Jenkins method involves the evaluation of the effects of an intervention into a system being monitored. It addresses the question of whether a measurable change took place as a result of a known intervention. It also answers questions concerning the nature and magnitude of such changes. The procedure is described by Box and Tiao (1975). They have named the method Intervention Analysis and have given extensive examples in the framework of ozone monitoring in downtown Los Angeles.

Intervention analysis can be of considerable value in studying the effects of known interventions on the monitored area. Changes in laws and regulations in areas far removed from a research natural area can have dramatic effects on the monitored site within the RNA. Often the exact date of a policy change is known. It remains to determine whether the research natural area has been affected, and if so, by how much. Intervention analysis can be a useful tool.

PUBLICATIONS CITED

Bloomfield, Peter. Fourier analysis of time series: an introduction. New York: John Wiley and Sons; 1976. 258 p.

Box, George E. P.; Jenkins, Gwilym M. Time series analysis forecasting and control. San Francisco: Holden-Day Co.; 1976. 575 p.

Box, G. E. P.; Tiao, G. C. Intervention analysis with applications to economic and environmental problems. J. Am. Stat. Assoc. 70(349): 70-79; 1975.

Duncan, Acheson J. Quality control and industrial statistics. Homewood, IL: Richard D. Irwin, Inc.; 1974. 1030 p.

Finklin, Arnold I. Climate of Priest River Experimental Forest, northern Idaho. Gen. Tech. Rep. INT-159. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1983. 53 p.

Grant, Eugene L.; Leavenworth, Richard S. Statistical quality control. New York: McGraw-Hill; 1980. 684 p.

Hall, Ronald J.; Likens, Gene E.; Fiance, Sandy B.; Hendrey, George R. Experimental acidification of a stream in the Hubbard Brook Experimental Forest, New Hampshire. Ecology 61(4): 976-989; 1980.

Hanson, C. L.; Wight, J. R.; Smith, J. P.; Smoliak, S. Use of historical yield data to forecast range herbage production. J. Range Manage. 35(5): 614-616; 1982.

IMPORTANCE OF BASELINE INFORMATION TO THE RESEARCH NATURAL AREA PROGRAM

Russell M. Burns

ABSTRACT: The Forest Service has knowledge gained from establishing research natural areas for almost 60 years. It found that baseline information essential for all monitoring activities is costly to accumulate. One relatively inexpensive method is suggested. Increasing scarcity of pristine representative examples mandates that each use of an area be carefully planned so that the RNA's will not be lost to future generations of researchers.

The Forest Service has been involved in the research natural area program for more than 55 years. It all started with a 1912 Act of Congress that directed the Secretary of Agriculture to select, classify, and segregate lands within the National Forests that were suitable for homestead entry. In compliance with the provisions of that Act, Forest Ranger J. A. Frieborn in 1926 examined a 4,464 acre tract of land adjacent to the Mt. Lemmon Recreational Area on the Coronado National Forest in Arizona. He found it to be not valuable for agriculture and, therefore, not subject to segregation under the Act. However, the lands were viewed as having value for timber production and streamflow protection and to contain cover of such a character that it would be in the public interest to keep the area in its present state so that the flora could be studied by the Natural History Society of Tucson, Arizona, and other scientific organizations. Accordingly, on March 23, 1927, Acting Secretary of Agriculture R. W. Dunlap issued a Land Classification Order designating the tract of land as the Santa Catalina Natural Area. The order stated that the natural area was to be "so managed as to permit scientific studies of forest growth." The Forest Service had its first research natural area.

At last count there were approximately 440 research natural areas (RNA's) administered by eight Federal land managing agencies. Coordination of the national program among agencies is through the Federal Committee on Ecological Reserves (FCER). A Directory of Research Natural Areas on Federal Lands of the United States of America authored by the FCER and published in 1977 listed 389 RNA's located in 46 States and one territory, totaling about 4.4 million acres. The primary emphasis at that time was to identify and establish new areas so as to capture representative areas before they were utilized for other purposes, and their pristine condition was lost. This remains one of our principal objectives. However, the objective is not solely to assemble a collection of pristine areas. Research natural areas are meant to be used, and unless they are used, a collection of areas in and of itself serves no useful purpose.

Listed in the directory are the two primary purposes for developing a comprehensive and representative system of research natural areas. The first is "to preserve a representative array of all significant natural ecosystems and their inherent processes as baseline areas." The second is "to obtain through scientific education and research, information about natural system components, inherent processes, and comparisons with representative manipulated systems." The collection of baseline data, monitoring ecological change, and monitoring effects of resource management are all goals of the program.

We have heard about various types of monitoring activities being conducted in the Northern Rocky Mountain States and in the Pacific Northwest and for a short time were able to vicariously share the problems and accomplishments of the speakers. It is gratifying, indeed, to hear that our research natural areas are being utilized and that monitoring is under way. The RNA program may have had its genesis in 1927 but it has only been in comparatively recent times that many of the RNA's have been used for monitoring.

Baseline data are needed for virtually every purpose to which RNA's are put. These data are essential for monitoring of every sort. Therefore, it would seem logical to assume that establishment of an RNA would be contingent upon gathering this information, and that resources for this task would be part and parcel of the formal designation process. Unfortunately, this is not true in the Forest Service nor do I believe it to be true in any of the seven other land-managing agencies.

Russell M. Burns is Principal Research Silviculturist in the Timber Management Research Branch at the Washington, D.C. Office of the USDA Forest Service, Washington, D.C. He coordinates the Forest Service Research Natural Area Program.

Furthermore, no matter how laudible and practical the collection of baseline data may sound, it is not likely to become true in the near future.

There are several reasons why there should be no conditions restricting the establishment of new RNA's. Probably most important is that such a provision would scuttle or at least seriously undermine the entire RNA program. In the Forest Service portion of the network we have 149 RNA's. However, we do not as yet have even one example of 62 of the 145 forest types listed by the Society of American Foresters. And of the 83 forest types that we do have represented, we have only one example of only 28, which means that for these 28 forest types there is no insurance against catastrophic loss. We need redundancy. In the best of times, RNA's are not high priority items in Agency, Regional, or Forest budgets. In times of budgetary constraint even fewer RNA's are established. Any impetus gained through the realization that pristine examples of a representative type are becoming scarce at an increasingly rapid rate is lost if financial stipulations, such as those mandating gathering baseline data, are placed on establishing new RNA's.

How then can we get the monitoring phase of the RNA program moving without seriously impeding establishment of new areas? One thing we can continue to do during these times of tight budgets is to complete the network and introduce redundancy into the RNA system. Another is to convince prospective users of RNA's of the importance of systematically acquiring, recording, and sharing baseline data. But probably the most profitable thing we can do is to demonstrate the importance of RNA's to prospective user groups and thereby gain their support either in financing the work or in actually gathering the data.

There is a large prospective user group out there that has either never heard of RNA's or that is not fully aware of the potential use and advantage to which RNA's can be put. They must be contacted and be made aware. Within the Forest Service the largest potential user of RNA's and the one that should benefit most from their use for monitoring is our National Forests. The National Forest Management Act (NFMA) of 1974 requires monitoring of all resource management activities to insure that no permanent damage is done to the productivity of managed sites. The Act does not, however, mandate that the monitoring be done on RNA's. It may be done on any suitable site. Therefore, it behooves those of us in the Forest Service to demonstrate the advantages of using RNA's in lieu of other areas for monitoring if we want support and resources from our National Forests.

Advantages of using RNA's for monitoring are manifold. They include:

o - the convenience of not having to locate new areas each time a new activity is to be monitored

o - lower costs because baseline data collected for monitoring one activity is equally applicable for monitoring other activities

o - increasingly broader application as the data base is expanded

o greater accuracy as the data base is continuously updated and refined

o - use of the RNA as a forum wherein researchers and their administrative counterparts may cooperate in projects of mutual concern and benefit

We should be able to look to outside sources for assistance as well. RNA's are established for approved, nonmanipulative research and education by qualified users or user-groups. All costs of locating, establishing, protecting, and administering RNA's are borne by the land management agencies. The land management agencies are the principal beneficiaries of their use, but they are not, or need not be, the sole beneficiaries. Opportunity exists for involving the university community to a greater extent. Grants and cooperative agreements are two vehicles whereby the agencies may tap the expertise and trained resources of our research counterparts in academia and enable them to participate more fully in the process--to our mutual benefit. From the amount of monitoring we heard about earlier, there certainly must be other strategies for gaining support for this work. If anyone has a successful method I would welcome hearing of it so that I may share it with others, nationwide.

Before we all rush out and start gathering baseline data or start making arrangements to have it done, I would like to voice some words of caution. A great deal of time, money, and effort has gone into identifying and establishing each research natural area. This investment is meant not only for the present generation of researchers and educators but, more importantly, for many generations of users yet to come. Let us be certain that we pass the RNA's on in as good a shape as when we first established them. This means that when we gather baseline and monitoring data we employ those methods that have the least adverse impact on the RNA. Researchers tend to be under self-imposed deadlines and schedules to get a job done and for this reason often employ an expeditious rather than a less harmful and more time consuming action or method, a soil pit, for example, instead of a bore hole.

When next you are out on an RNA preparing to undertake some nonmanipulative research, ask yourself if a less harmful method may be employed. If there is one, use it, regardless of the added time or inconvenience involved. We do not have the luxury of doing less and moving on to a comparable area. There may not be one.

RNA's are not ours to abuse, not even in the slightest. Consider each as you would a threatened species, and treat it accordingly. Let us not number ourselves among those who hunted the last of the carrier pigeons or destroyed the habitat of the ivory-billed woodpecker. It is becoming increasingly unlikely that we will ever find, and be able to reserve, such pristine representative areas again.

Section 2. Successful Monitoring Programs

INTEGRATING ACADEMIC AND AGENCY RESEARCH INTERESTS AT THE H. J. ANDREWS EXPERIMENTAL FOREST

Arthur McKee

ABSTRACT: A large number of studies are conducted at the H. J. Andrews Experimental Forest and seven nearby research natural areas (RNA's). During 1983, 63 academic and 21 agency scientists were involved in 56 separately funded projects. In addition, 48 graduate students used the areas. Data from various monitoring efforts were used in 79 of the total number of studies, including 21 studies conducted on RNA's. Several factors appear responsible for the success of the monitoring program that combines academic and agency research interests. The factors are: a vigorous research program, common research interests and goals, a spirit of cooperation among the scientists, a coordinating administrative structure, clearly defined responsibilities, and a centralized data bank.

INTRODUCTION

The H. J. Andrews Experimental Forest was established in 1948 by the U.S.D.A. Forest Service for the purpose of examining the effects of different logging methods on forest regeneration and water quality. Because hydrologic and forest successional studies require long-term measurements, monitoring efforts were started along with the earliest research. During the 1950's and 1960's scientists initiated several meteorological, forest succession, erosion, and nutrient cycling studies.

Many of these studies collected data of a long-term nature, or provided the basis for establishing a long-term monitoring program. The Andrews Forest, by which term the seven nearby research natural areas are collectively included with the H. J. Andrews Experimental Forest, was selected in 1970 as an intensive study site by scientists of the Coniferous Forest Biome (U.S. International Biological Program) because of the existence of the rich data base.

The research program at the Andrews Forest changed dramatically in two significant ways as a result of this selection. The first of these changes was the shift from nearly exclusive use of the site by U.S.D.A. Forest Service scientists to use by a cadre of researchers affiliated with agencies, universities, or both. That shift has continued to this day, with the proportion of university scientists and research projects gradually increasing to where they now predominate (table 1). About two-thirds of all research projects in 1983 were funded through various universities. Concomitant with this shift has been an increasing and substantial use by graduate students (table 2). The second significant change was the development of multidisciplinary ecosystem studies by scientists of the Coniferous Forest Biome project, which integrated both agency and university research. This prompted the creation of a coordinated monitoring program to provide the necessary long-term data sets of common interest to this diverse group.

Large, interdisciplinary research projects are the dominant type of research conducted today at the Andrews Forest. In addition, there are several smaller projects addressing specific problems. Studies of both types contribute to, and rely on, the monitoring program. Since its inception during the Coniferous Forest Biome research, the monitoring program has enlarged in scope and improved in organization. Its success appears to be the result of several factors.

DISCUSSION

The reasons for long-term ecological data collections are manifold and the utility of such data is increasingly recognized. Data collected by a monitoring program provide a measure of the natural variation in an ecosystem and permit an examination for long-term trends and changes. Such data facilitate analyses of ecosystem processes and development of ecological theory. They make possible an accurate assessment of the effects of anthropogenic pollutants. If more data were available, environmental impact statements would have more credibility, and regional and local land-use plans could be more effectively developed by the land manager. For these reasons and others, Gene Likens, past president of the Ecological Society of America, argues that the establishment of long-term studies and high-quality monitoring programs is a major priority for ecological research (Likens 1983).

A significant part of the difficulty in establishing a monitoring program is deciding what factors or components of the ecosystem should be measured. What data sets will be most useful in the future? Several conferences were sponsored by the National Science Foundation in the late 1970's to address that question (Botkin 1977, 1978; TIE 1979a, b). The reports provide lists of suggested measurements but offer little advice on how to establish and maintain a monitoring program. The following discussion

Arthur McKee is Research Instructor in the Forest Science Department, Oregon State University, Corvallis.

Table 1--Number of research projects at the H. J. Andrews Experimental Forest and nearby research natural areas during 1983

Subject area[1]	Number of research projects: University	Agency	Total	Utilizing monitoring program
Animal ecology	6	3	9	3
Ecosystem processes	16	5	21	11
Entomology	17	3	20	3
Fisheries	1	1	2	2
Genetics	1	1	2	2
Geology	3	3	6	3
Hydrology	1	2	3	3
Limnology[2]	7	0	7	5
Plant ecology	8	4	12	9
Silviculture	6	9	15	10
Soils	0	1	1	0
Totals	66	32	98	51

[1]Within a subject area, the numbers of university funded projects, agency funded projects and projects utilizing the monitoring program are presented with total number of projects.

[2]Including riparian ecology.

Table 2--Number of graduate student projects at the H. J. Andrews Experimental Forest and nearby research natural areas during 1983

Subject area[1]	Number of graduate student projects: University	Agency	Total	Utilizing monitoring program
Animal ecology	2	1	3	2
Ecosystem processes	8	0	8	4
Entomology	5	0	5	2
Fisheries	4	0	4	2
Geology	1	2	3	2
Hydrology	0	2	2	2
Limnology[2]	3	0	3	3
Plant ecology	7	2	9	4
Silviculture	4	2	6	3
Soils	2	0	2	2
Tree physiology	3	0	3	2
Totals	39	9	48	28

[1]Within a subject area, the numbers of university funded projects, agency funded projects and projects utilizing the monitoring program are presented with total number of projects

[2]Including riparian ecology.

offers some advice based on the experience gained in developing the monitoring program at the Andrews Forest. Although each site will have its own unique needs and problems, there appear to be some common factors or key ingredients in a successful program. By fostering the development of these common factors, a group interested in long-term monitoring will be a long way toward resolving what to measure and how to maintain the program.

The common factors of a successful monitoring program are: (1) a diverse and vigorous research program; (2) common research goals or interests; (3) a spirit of cooperation or willingness on the part of researchers to share responsibilities and data; (4) an administrative structure to coordinate the monitoring activities; (5) clearly defined responsibilities for collection and maintenance of data; and (6) a central data bank. Stable financial support is a major factor, but if all the other ingredients are there, the financial issues become largely a matter of coordination.

The first factor listed--a diverse, vigorous research program--is perhaps the most important ingredient for success. The mixture of research projects at a site will, to a large extent, determine the measurements to be made and should provide the basis for the logistical and financial support. By coordinating the needs and resources of the various research projects, economies of scale emerge and responsibilities can be delegated. Monitoring activities that are not integral parts of research programs and have to stand on their own accomplishments will have a more difficult time competing for limited research funds.

The research program at the Andrews Forest is large and diverse. During 1983, 63 academic scientists, 21 agency scientists, and 48 graduate students worked in 56 separately funded projects. The varied nature of the research is shown in table 1, which divides the 56 separately funded projects into subprojects by subject area. Table 2 shows the variety of graduate student projects. The existing monitoring program at the Andrews Forest (table 3) has been determined by the long-term research needs of previous and current scientists. That it is an important part of the overall research effort is obvious from tables 1 and 2, which show that 51 of the 98 research projects and 28 of the 48 graduate students utilized data from the monitoring program in 1983. Twenty-one of the 79 projects that used data from the program were located on research natural areas. The components or factors presented in table 3 include all those recommended in the TIE (1979b) report listing core requirements for a long-term ecological research program. The monitoring program at the Andrews Forest has grown in step with the increased diversity of research projects and would be far less complete with a smaller research effort.

Table 3 also shows the relative responsibility of agency and university research projects for the different components. Many factors are being measured by both groups and the data sets merged. This reveals the degree to which research interests are held in common by agency and university scientists. It also indicates the spirit of cooperation among the scientists because the data collected become freely available to all.

A large monitoring effort clearly needs to be coordinated. The coordination of monitoring activities at the Andrews Forest was first done in an informal manner with principal investigators pooling resources and data from their own research projects. The research activities had increased so much by the mid-1970's that this informal type of coordination was proving impractical. In 1977, the administrative structure shown in figure 1 was established and has since proven effective. The site manager has primary responsibility for the coordination of the monitoring program. The questions of what components or factors to measure, methods to be used, and frequency of sampling are addressed by the Local Management and Policy Committee. This committee is composed of both university and agency scientists who have research projects at the Andrews Forest. The committee also provides the continuity necessary to maintain a long-term ecological measurements program derived from research projects that ordinarily have a limited time span.

The Local Management and Policy Committee also helps define who is responsible for the different measurements. This is important in a program of this magnitude where several projects may have an interest in a data set, but for reasons of efficiency just one or two projects may be conducting the sampling. Along with the site manager, the committee helps maintain quality control by specifying the standards to be met.

The last of the common factors for a successful monitoring program is a central data bank. Other terms sometimes used for central data bank are data management center or quantitative services group. All data sets collected as part of a monitoring effort should be well documented, carefully edited, and readily available. The experience at the Andrews Forest has been that a well supported data bank, staffed with qualified people who are dedicated to data management, is essential. The monitoring program at the Andrews did not work well during the period when individual investigators were responsible for editing and archiving their own data. The standards of documentation varied greatly from researcher to researcher but generally were inadequate. Delays were common in obtaining requested data. A gradual appreciation of the benefits of having a central data bank resulted in the development and establishment of our current facilities.

Table 3--A summary of the monitoring program at the H. J. Andrews Experimental Forest and nearby research natural areas showing relative responsibility of agency and university research projects for each component

Component or factor monitored	Collected or measured by agency	Collected or measured by university
Site description and background:		
Historical record	A	U
Geologic maps	A	U
Soils maps	A	u
Flora	A	U
Fauna	a	U
Meteorological and physical:		
Shortwave radiation	a	U
Net allwave radiation	a	
Air temperature	a	U
Water temperature	A	U
Dewpoint		U
Wind speed		U
Wind direction		
Precipitation	A	U
Snow depth and duration	a	U
Soil water content	A	u
Groundwater level	a	U
Watershed discharge	A	U
Erosion and sediment load	A	U
Stream morphology	A	U
Streamwater transparency		
Ice cover of stream		
Chemical measurements:		
Atmospheric--		
Wetfall	a	U
Dryfall		U
Particulates		
Gases		
Terrestrial--		
Vegetation	a	U
Litter (including heavy metals)	a	U
Soil	A	U
Soil solution	A	U
Aquatic--		
Streamwater	A	U
Litter	a	U
Vegetation		U
Invertebrates		U
Primary production and decomposition:		
Terrestrial--		
Leaf area index	a	U
Standing crop (including phenology)	A	U
Litterfall		U
CO_2 release from soil		
Carbon Retention	a	U
Aquatic--		
Phytoplankton		u
Periphyton	a	U
Macrophyte		U
Carbon retention	A	U
Population records:		
Terrestrial--		
Plants	A	U
Amphibians		u[1/]
Birds		u[1/]
Mammals	a	u[1/]
Aquatic--		
Zooplankton		u
Benthos		U
Fish	a	U

Capital letters denote a greater responsibility than lower case. The listing includes all components recommended by TIE, Institute of Ecology (1979b) for a long-term ecological measurement program.

1/ Component is not being sampled at frequency or level recommended by TIE (1979b) report.

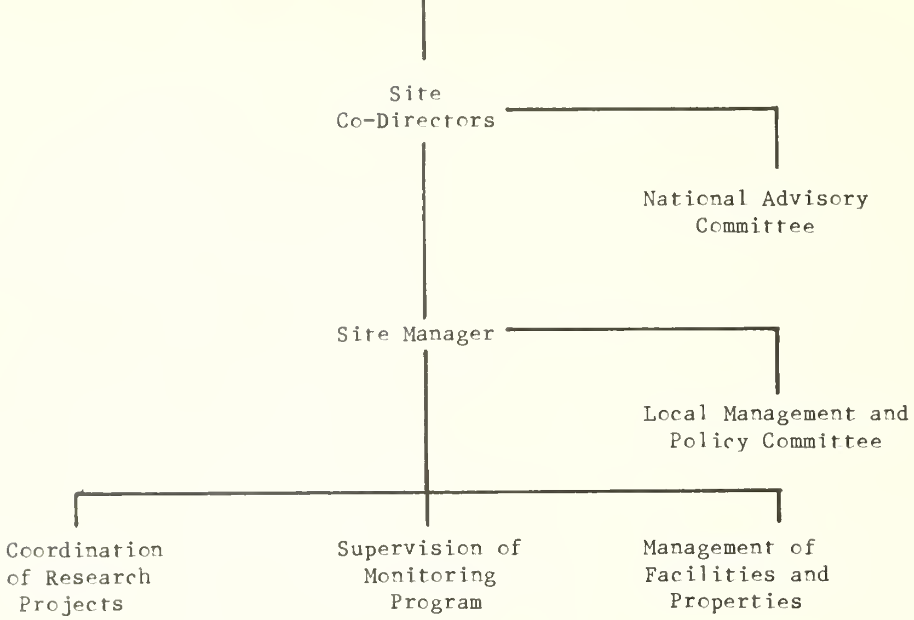


Figure 1.--The administrative structure of the research program at the H. J. Andrews Experimental Forest and associated research natural areas.

Data are now readily available, with the assurance they have been carefully edited and are well documented. The data management people also provide statistical analyses, assist in experimental design, and help the scientists with a variety of quantitative services.

The data bank has grown beyond the immediate needs of the scientists working at the Andrews Forest and is now a center for data management of several departments at Oregon State University. Its own success is a reflection of the value of the services it performs. This is not meant to suggest that each site needs such a large investment in a data bank. The message is clear, however, for any monitoring effort: do not ignore the needs and costs of maintaining quality data and have someone in charge of documenting, entering, and editing the data.

CONCLUSION

The monitoring program at the Andrews Forest developed over several decades, evolving from a sampling program that was quite limited in scope to the large, coordinated program of today. Research interests have always determined the monitoring program that has provided the long-term ecological measurements of common interest to scientists.

Several factors have contributed to the successful establishment of the program. These are probably common to any similarly successful monitoring effort. The factors are: a vigorous research program, common research interests and goals, a spirit of cooperation, a coordinating administrative structure, a clear definition of responsibilities, and a centralized data bank. Some of these are intangibles and difficult to establish. A spirit of cooperation and common research goals are not off-the-shelf items. They require considerable care in nurturing and, once established, require continual attention. In a program of this magnitude coordination would be impossible without cooperation.

PUBLICATIONS CITED

Botkin, D. B., chairman. 1977. Long-term ecological measurements. Report of a Conference. Woods Hole, Massachusetts. 16-18 March 1977. Prepared for the National Science Foundation, Washington, D.C., U.S.A.

Botkin, D. B., chairman. 1978. A pilot program for long-term observation and study of ecosystems in the United States. Report of a Second Conference on Long-term Ecological Measurements. Woods Hole, Massachusetts. 6-10 February 1978. Prepared for the National Science Foundation, Washington, D.C., U.S.A.

Likens, G. E. 1983. A priority for ecological research. Bull. Ecol. Soc. Am. 64(4): 234-243.

TIE, The Institute of Ecology. 1979a. Long-term ecological research. Concept statement and measurement needs. Summary of a Workshop. 25-27 June 1979. Prepared for the National Science Foundation, Washington, D.C., U.S.A.

TIE, The Institute of Ecology. 1979b. Guidance documents for long-term ecological research. Preliminary specifications of core research measurements. A Final Report to the National Science Foundation, Grant DEB7920243. The Institute of Ecology, Indianapolis, Indiana, U.S.A.

BIOLOGICAL MONITORING: THE NATURE CONSERVANCY'S PERSPECTIVE

Steven C. Buttrick

ABSTRACT: The Nature Conservancy works to protect natural diversity through a balanced program of identification, land protection, and management. Biological monitoring is an important component of the Conservancy's management program. Because monitoring can be very resource consumptive, the decision to monitor is made conservatively. The Conservancy initiates a monitoring program for four reasons: 1. to fulfill legal obligations, 2. to determine responses to management practices, 3. to track threats, and 4. to measure overall protection goals. In all cases the focus of the monitoring is the element (rare species or community) and not the preserve or natural area.

INTRODUCTION

The Nature Conservancy is a nonprofit private conservation organization committed to the preservation of natural biological diversity. The Conservancy works to accomplish this goal through a balanced program of identification, land protection, and management. Identification involves the selection of species and communities most in need of protection and is primarily accomplished through state-based inventories called Heritage Programs. To date, these inventories have been established in 35 states to identify which species and communities are rare or endangered and to locate the best occurrences of these. This identification process provides the information needed to make land protection decisions. Land protection involves bringing critical habitat under some form of legal protection. But land protection, whether through registration, conservation easement or fee acquisition, cannot alone assure the long-term preservation of the species or communities of interest. These critical elements are still subject to ecological changes such as succession and various disturbances both natural and anthropogenic and thus can require management attention. The Nature Conservancy's stewardship program is responsible for providing adequate management for the species and communities that occur on Conservancy preserves and are both endangered and in need of management. "If we fail in this task, the identification and protection efforts that preceded it have been wasted" (Blair 1983).

Steven C. Buttrick is the Assistant Director of Stewardship at The Nature Conservancy in Arlington, Virginia.

Resources (including money, time, and personnel) available for conservation are extremely limited. The Conservancy effectively uses its resources by concentrating protection efforts on only those species and communities most in need because of rarity or threat. The stewardship program applies this same orientation to its management activities. This is done by focusing resources on elements that are not only rare but will also benefit from our efforts.

Monitoring, the identification and measurement of change over time, can play an important part in any biological management program, by identifying when management intervention might be needed and tracking the success of management actions. Monitoring, however, can involve a large commitment in time, labor, and money and thus warrants careful consideration before being initiated.

The Nature Conservancy has been trying to use biological monitoring as a cost effective tool on its preserves by seriously considering the policy questions of why monitor, what to monitor, and when to monitor. At the present time the topic of how to monitor has not been adequately addressed. The policy issues must be resolved first to ensure that monitoring programs are addressing the right questions and are only developed when the information is needed to further Conservancy goals.

WHY MONITOR?

The first question to be addressed is: Why monitor? The Conservancy will begin a monitoring program for four reasons.

<u>To fulfill legal obligations</u>.--Occasionally, the Conservancy will lease certain rights of a preserve such as haying or grazing to a second party or receive a piece of property encumbered with a lease or restrictive covenants. In such cases the Conservancy must monitor because of a legal need to determine whether rights retained by an original owner or leased by us to a second party are adversely affecting the elements we are seeking to protect. Monitoring and baseline data collection must be detailed and accurate because the information generated must be able to stand up in a court of law.

To determine responses to management practices.--The second major reason for the Conservancy to initiate a monitoring program is to assess the effect of our management practices on the species and communities of interest. The Conservancy begins this process by evaluating the management needs of all rare elements on its properties. Based on these needs preserve management decisions are made. Because very little is known about the ecological requirements and associated management needs for the majority of rare species and communities, it is often necessary to monitor the effects of a particular management treatment or to conduct research designed to identify the treatments that are most effective in maintaining or improving the condition of the rare element in question.

To track actual or potential threats.--Threats that we might wish to keep track of include pesticide drift from adjacent lands; exotic or feral species; agricultural run-off including silt, pesticides and fertilizers; water draw-down from heavy agricultural or residential use; water pollution from upstream actions; and even acid rain. Many of these threats should be addressed prior to any land protection effort because they could affect the overall viability and defensibility of the element to be protected at the site and thus affect the overall design of the preserve.

To measure progress toward overall protection goals.--The final reason to monitor is to measure the overall success of our protection efforts. As stated earlier, the Conservancy works by protecting habitat for the most endangered species and maintaining the best representative examples of the country's natural communities. These species and communities can be looked at as biological investments that the Conservancy has made. In this context, the major function of biological monitoring is to determine whether these investments are maintaining their value over time. This type of monitoring is a simple auditing function, asking whether species populations protected on Nature Conservancy preserves are increasing, decreasing, or stable over time, or whether protected communities are recovering, stable or changing due to succession or other natural or anthropogenic processes. Another objective is to serve as an early warning system to notify us of needed management intervention.

WHAT AND WHEN TO MONITOR?

The focus of all biological monitoring within The Nature Conservancy is the element, that is, the endangered species or community protected on a preserve. Each of the four reasons to monitor is centered around protected elements. We monitor, then, important species and communities protected on our preserves, indicators of these elements, conditions necessary for their maintenance, and specific threats to these elements.

The important point to be made here is that the focus of the monitoring is not the preserve or natural area. In the past general preserve monitoring was occasionally carried out. This monitoring, whether done quantitatively through transects and quadrats or on a more qualitative basis through photo points, was often done simply to detect change without any clear motive or intent. Similarly, monitoring to determine community dynamics or ecosystem function unassociated with management needs, although of great importance, is peripheral to The Nature Conservancy's goal of element preservation. Although the Conservancy will not direct its resources to nonelement centered monitoring, it does actively encourage use of its preserves by academic institutions and individuals interested in conducting short- or long-term ecological research. Nature Conservancy preserves such as California's Santa Cruz Island, Northern California Coast Range Preserve, and Mexican Cut in Colorado have extensive research and monitoring programs being carried out by government and academic researchers.

Within The Nature Conservancy's portfolio there are approximately 800 preserves encompassing 400,000 acres over which we have direct management responsibility. These preserves contain well over 3,000 populations and stands of endangered species and communities. The Conservancy does not have the resources needed to monitor all these elements, at least in any quantitative fashion. To address, specifically, which elements will be monitored, when and how, the Conservancy must apply the principle of triage. According to the American Heritage Dictionary of the English Language, triage is defined as a system designed to produce the greatest benefit from limited treatment facilities for battle-field casualties by giving treatment to those who may survive with proper treatment and not to those with no chance of survival and those who will survive without it. The same concept can be applied to any similar system used to allocate a scarce commodity or resource only to those capable of deriving the greatest benefit from it. To make the decision for when and what to monitor the following factors should be considered: element selection, demonstrated need, and element manageability.

These factors have to be considered at two levels: which elements most need and will benefit by monitoring and which occurrences of these elements (populations or stands) most need and will benefit.

Element selection is critical because not all species and communities protected by the Conservancy are equally endangered or threatened. The Conservancy has developed a procedure for assigning importance or endangerment ranks to elements. These ranks take into

consideration taxonomic uniqueness, total distribution, total number of occurrences protected and unprotected, ecological fragility, threat, and persistence. High-ranked elements and specific threats to high-ranked elements should receive first consideration when allocating monitoring resources.

Establishing a demonstrated need to monitor is a more difficult factor. In its preserve management planning process the Conservancy addresses this question each year on an element by element, preserve by preserve basis, the results of which are stored and managed in a computerized data base. High-ranked elements, protected on our preserves that are not currently threatened or whose response to active management is well known, receive a low monitoring priority. Seral communities and endangered species restricted to these communities warrant monitoring consideration as well as those elements where the need for active management has been identified but responses to different management practices are unknown. In the majority of cases very little is known about habitat requirements or management needs of high-ranked elements. Before initiating monitoring or research programs, the Conservancy attempts to pull together known management related information about a particular species or community, file it in a centralized element file, and summarize it in a newly developed computerized document called an Element Stewardship Abstract. The abstract is a synthesizing document serving three important functions. First, it identifies information gaps and targets future research efforts. Second, it provides a standard format for highlighting the specific information about a species or community that helps determine its management needs. Finally, it allows the Conservancy to readily communicate management information among different preserves, state offices, regional offices, and Heritage Programs. In this way we avoid duplicative research while increasing our management capabilities.

The third factor, manageability, is a pragmatic one. It forces us to ask whether we should monitor a particular occurrence of an element if we already know that we either cannot successfully manage it or do not wish to manage it. An example of the latter situation is an old growth white pine stand in Connecticut. Here we are dealing with an over-mature seral community and the decision would probably be made to let succession take its course. Documenting the demise of this magnificient stand through constant monitoring might be of academic interest but it does not appreciably further our goal of natural diversity preservation.

While many species and communities may warrant monitoring, certain protected occurrences of them (populations and stands) may not. Many populations of endangered species protected in the past are simply inviable due to low population levels or habitat alteration. Similarly, many stands are so degraded that restoration is not feasible or cost effective. Inviable or indefensible populations or stands should not be allowed to drain limited conservation sources. The Nature Conservancy's new preserve selection and design procedures attempt to prevent low-quality occurrences from entering the Conservancy's portfolio.

MONITORING METHODOLOGY.

The last topic I wish to consider is monitoring methodology. The Nature Conservancy has a very liberal view on what qualifies as biological monitoring. To us, simply noting on a regular basis the presence or absence of a particular element does constitute a low level of monitoring. It is very important that the level or intensity of monitoring reflect the importance of the element being monitored and the objective of the monitoring program. Thus, clear goals should be established before any monitoring program is established. Depending on the goals, the reasons for monitoring, and the importance of the element, the monitoring can either be qualitative or quantitative. Qualitative monitoring includes noting the presence or absence of an element on a regular basis and can be accomplished by any person, regardless of scientific training, who has the ability to identify the element in question. Permanent photo points sampled on a periodic basis also represent a level of qualitative monitoring frequently carried out on Nature Conservancy preserves. More detailed information can be collected using standardized field survey reports on a regular basis. During the preserve design phase of a protection project, field survey forms should be completed for each of the important elements we are seeking to protect. These forms are used to record basic abiotic, population, and compositional data that can serve as a baseline and can be used to compare the data recorded on field survey forms during subsequent visits to the site. At the present time most high-ranked species and communities on Conservancy preserves receive at least this level of monitoring through use of an extensive volunteer network. This qualitative monitoring can supply sufficient information to allow the Conservancy to measure the status of protected elements throughout its portfolio and often to alert us to potential management problems.

When more detailed data is needed, quantitative monitoring is preferred; but as the monitoring scheme increases in complexity so does the demand for time and financial commitment. A simple census can be used for many plant and animal populations. Because we are dealing with rare species, frequently all individuals of a population can be counted easily and different measurements made on each individual or certain tagged ones. When dealing with communities or larger populations, permanent plots and transects are often employed. Monitoring designs cannot be standardized, but must be tailored to fit the monitoring goal and the nature of the species,

community, or environmental factor being studied. The most intensive monitoring schemes are used when detailed, reproducible statistics are required.

The following section describes a few biological monitoring programs that illustrate some of the reasons for monitoring described in the beginning of this paper as well as different levels of monitoring intensity.

EXAMPLES

A detailed monitoring program is warranted when the data generated must be able to stand up in a court of law. The Katharine Ordway Sycan Marsh Preserve in Oregon is a case in point.

This 24,000 acre preserve, acquired in 1980, came encumbered with a 40-year grazing lease that stipulates that the condition of the marsh can not be degraded. The area was acquired to protect, among other things, upland sandpipers, sandhill cranes, and outstanding examples of communities of Cusick's bluegrass and tufted hairgrass. The major question for preservation of the area was whether the important species and communities for which the marsh was protected were changing or being degraded due to grazing and irrigation practices. In 1982 the Conservancy collected the necessary baseline information to establish the condition of the marsh (TNC 1982), and concurrently set up a monitoring system to document any changes in the baseline. Because the magnitude of the marsh precludes monitoring each community in each pasture and all faunal species of concern, it was decided that a few communities and a couple of bird species would best serve as indicators of change due to irrigation and grazing.

The tufted hairgrass community was emphasized in the sampling because it contained species of high palatability, contained dominant species of caespitose growth form (caespitose species are thought to reflect grazing utilization impact better than rhizomatous species), was widespread, in a relatively high ecological condition, and would reflect significant changes in ranching practices. The communities were quantitatively described using a series of permanent transect clusters. Each cluster contained three permanent 25 m transects located in parallel at 3 m intervals. Total basal area, density, and size class distribution of caespitose grass basal tufts were measured in 20 X 50 cm microplots spaced at 1 m intervals along each transect. Frequency for all species was calculated using 7.07 X 7.07 cm loops spaced at 0.5 m intervals. To compare grazed with ungrazed transect clusters, two micro-exclosures (50 X 15 m) and two macro-exclosures (130 ha and 65 ha) were established and sampled. A sampling schedule has been set up to monitor any changes in the baseline.

To monitor the effects of ranching practices on the bird fauna of Sycan Marsh, two species were chosen as indicators, the black tern (Chlidonias niger) and the sandhill crane (Grus canadensis tabida). Black terns require surface water of varying characteristics throughout their reproductive cycle and represent the r-selection life-history pattern. Sandhill cranes require a diversity of habits ranging from open water for resting to tufted hairgrass communities for foraging and represent the K-selection life-history pattern.

In order to make marsh management inferences based on black tern population dynamics, in 1981 and 1982 baseline data were collected to determine the number of breeding black terns on Sycan Marsh, to document the hydrologic and vegetative characteristics of the nesting habitat, to determine reproductive success, and to describe habitat utilization. Similarly, baseline data were collected to determine the number of breeding pairs of sandhill cranes, to describe nest-site characteristics, to determine nesting success, the impact of research disturbance on nesting success and the annual recruitment to the fall flock. Each year the terns and cranes will be censused and their reproductive success assessed.

Monitoring to assess the effect of management practices on species and communities is well illustrated by the Conservancy's management research program at the Edge of Appalachia Prairies in Ohio. In 1959 The Nature Conservancy acquired Lynx Prairie, one of E. Lucy Braun's study areas, and the first of a series of preserves in Adams County, Ohio. Since then the Conservancy and the Cincinnati Museum of Natural History have added The Wilderness, Hanging Prairie, Buzzardroost Rock Preserve, and Abner Hollow, collectively called the Edge of Appalachia Preserve System. These preserves are significant because of the prairie openings they protect along with a complement of important prairie plants. Ohio prairie openings, once estimated to cover 2.5 percent of Ohio's landscape (Troutman 1979) are now reduced to about 100 acres (Cusick and Troutman 1978). The most obvious threat to the protected prairies is from woody species invasion, a problem well documented by aerial photographs taken from 1938 to 1971 (Annala and Kapustka 1983). Because of their geographic location, small size and unique habitat, prairie management techniques that are applicable to prairies in Iowa, Minnesota, or even other areas of Ohio may not be applicable in Adams County. In 1983, The Nature Conservancy and the Cincinnati Museum of Natural History developed a management research plan to evaluate a variety of management techniques on these prairie openings. The management goal is to reduce forest encroachment by removing invading woody species and to improve the overall quality of the prairies, especially as sites for rare and endangered plant species.

The research and monitoring plan briefly discussed below, is described in detail by Hirsh (1983). Three management treatments and one control are being used. The management

treatments are (1) March burns on a 2-year cycle, (2) June burns on a 2-year cycle, and (3) woody plant cutting. Sixteen prairie openings are being studied. Each treatment will be applied to four prairies. Rare plants, key prairie species, woody invaders and the prairie community in general will be monitored over a 4-year period to judge the effectiveness of the treatment methods. For rare plants, 13 species are being monitored. Twenty individuals were tagged on each of the 16 prairies and measured for height, aerial diameter, basal diameter, number of flowering stems, and number of seeds produced. Eight typical prairie species (four grasses and four forbs) are being monitored. Sixteen individuals per species per prairie have been marked and measured for height, basal diameter and number of flowering stems. Similarly, 16 individuals of four woody invaders have been marked and are being monitored for mortality, growth, and resprouting in each of the prairies. Quadrats are being used to monitor treatment effects on the community cover and physiognomy. Ten randomly placed, 1-m^2 quadrats are being used on all 16 prairies to record percent cover of all grasses combined, all forbs combined, all woody plants combined, and bare ground and general physiognomy. In all four cases (communities and rare, key, and woody species) the data were collected at three times during the growing season and monitoring will be carried out three times yearly.

The following examples represent qualitative or low-intensity quantitative monitoring conducted primarily to track the overall success of our protection efforts in Wisconsin. On Schluckebier Sand Prairie because of the rarity of *Lespedeza leptostachya* we are able to count the number of clones, the number of individuals per clone, and record heights. Similarly, the number of stems of *Cypripedium candidum* occurring on both Summerton Bog and Snapper Prairie where there are active prescribed burning programs, can be accurately counted each year. The number of individuals of glass lizard, box turtle, and 5 lined-race-runner are counted every year at Spring Green. Visual changes in wet prairie, fen, oak-opening, wet-mesic prairie, dry-mesic prairie, and sedge meadow all in Chiwaukee Prairie, Wisconsin, are recorded through annual photographs taken from permanent photo points. In some other states, aerial census has been used effectively. Sandhill cranes are censused from the air at Mormon Island, Nebraska, and bald eagle nests are similarly censused in Maine on nine island preserves. On Schwamberger Preserve in Ohio, 16 plant species are monitored yearly using the field survey forms. These are just a few of the low-intensity monitoring programs representing a yearly census of the species and communities protected on Conservancy preserves.

The Conservancy does not have the resources needed to monitor all of the over 3,000 populations and stands of endangered species and communities protected on its preserves. To address the questions of when, how, and which elements will be monitored, the Conservancy applies the principle of triage, a system used to allocate a scarce commodity, in this case conservation resources, only to those capable of deriving the greatest benefit from it. Elements to be monitored should be high ranked (endangered and threatened) and have a demonstrated need for monitoring such as being highly threatened, seral, or occurring in a seral community. Monitoring should also be carried out when active management is needed but responses to different management practices are unknown. Inviable or indefensible populations or stands should not be allowed to drain limited conservation resources.

Monitoring methodology should be tailored to the nature of the element and the overall reason for monitoring. Monitoring methodology can be as simple as a yearly recording of presence or absence or as intensive as needed to establish and document a management research program or provide statistically reproducible data to protect The Nature Conservancy's legal interests.

PUBLICATIONS CITED

Annala, A.; L. A. Kapustka. 1983. Photographic history of forest encroachment in several relic prairies of the Edge of Appalachia Preserve System, Adams County, Ohio. Ohio J. Sci. 83: 109-114.

Blair, W. D., Jr. 1983. Presidents Letter. The Nature Conservancy News. 33(4): 4.

Cusick, A.; K. R. Troutman. 1978. The prairie survey project--a summary of data to date. Ohio Biol. Surv. Inform. Circ. No. 10. 60 p.

Hirsh, D. W. 1983. Management Research: Edge of Appalachia Prairies. A Research Proposal to The Cincinnati Museum of Natural History. Ohio Nature Conservancy Field Office, Columbus, OH 22 p.

The Nature Conservancy. 1982. Sycan Marsh Baseline Report. Oregon Field Office, Portland, OR. 174 p.

Troutman, K. R. 1979. Relicts of the Past: Prairies, p. 132-141. In M. B. Lafferty, ed. Ohio's Natural Heritage. Ohio Academy of Science Columbus, Ohio.

Section 3. Management Problems

PANEL ON FIRE MANAGEMENT IN RESEARCH NATURAL AREAS: SUMMARY COMMENTS

Bruce M. Kilgore

Determining the appropriate role for fire in any given research natural area (RNA) requires two things:

1. Knowledge about the ecological conditions and processes involved in the RNA
2. Clearly stated management objectives

While we would normally expect to maintain natural conditions in an RNA by allowing natural processes to occur, this is not always possible in the real world. This is especially true where natural fire is concerned because RNA's tend to be small and often are surrounded by commercial resource lands. Hence, deliberate manipulation is usually required to maintain a semblance of "natural" conditions, either by using scheduled prescribed fires or by suppressing natural fires. Such manipulation is always aimed at maintaining the unique vegetation type or feature the RNA has established to protect or perpetuate. This prompts me to comment briefly on terminology.

Too often the point seems overlooked that suppressing fires is manipulation just as surely as use of human-ignited prescribed fire (scheduled ignitions) is manipulation. Both have their place in management strategies, but both are unnatural. So to adhere to strict natural area management concepts, we would have to literally do nothing. Even then, unless natural lightning ignitions from outside our small RNA's (or wilderness or parks) are allowed to burn into these areas (as they have done historically), we would have a human-modified system. Thus the best we can do is to simulate natural conditions in RNA's and in other natural areas.

A second terminology problem involves the word "preservation" when this word is applied to dynamic vegetative ecosystems. We cannot (and would not want to) keep such ecosystems static. Instead we want to perpetuate their natural, dynamic condition. So I would propose the term "perpetuate" or "perpetuation" rather than "preserve" or "preservation" to describe our objective in using fire in RNA's and in other dynamic natural systems.

Bruce M. Kilgore, Biological Scientist with the USDA Forest Service, Intermountain Forest and Range Experiment Station located at the Northern Forest Fire Laboratory in Missoula, Mont.

It would appear that the Forest Service feels there is a quandry about whether our primary emphasis in managing RNA's should focus on perpetuating (or maintaining) vegetative structure and composition or perpetuating natural processes. The National Park Service seems to focus primarily on natural processes. The Nature Conservancy uses prescribed burning when and where it contributes to the goal of maintaining species and communities targeted for preservation (or perpetuation).

Ideally we would perpetuate both natural conditions and natural processes (Kilgore 1984). Chuck Wellner's (1984) concerns at the Wilderness Fire Symposium about the impacts of fire on undisturbed and climax stage vegetation in RNA's would support the need for careful focus on the objectives for which individual Research Natural Areas were established. Where the primary emphasis is on remnant stands of old-growth forests or sensitive rare, endangered, or threatened plant species (which would be damaged by fire), then a policy of fire exclusion would take precedence in order to preserve specific vegetation conditions or structural features. (Even here, this is a short-term view because most ancient stands were visited or even recycled by fire at intervals of 100 years or more.) On the other hand, in the majority of RNA's in the Inland West that were established to perpetuate a seral stage of succession or species that require such a stage for survival, prescribed fire may be needed to simulate the natural fire process.

This is particularly true where after a long period of fire exclusion, it may be essential to reduce litter or down woody fuel accumulations by carefully controlled prescribed burns. Because of the small size of most RNA's and the differences in management philosophy (in most cases) between the RNA and the neighboring landowners, allowing natural (lightning) fires to burn is usually not practical, even in those cases where the results of all natural processes are in keeping with the RNA objective. Here, it may be the best management strategy to simulate natural processes through use of prescribed burning, selecting as closely as possible a nearly "natural" season, frequency, intensity, and size of burn. Practical logistics and economics tend to nearly preclude any other approach to use of fire in RNA's.

We are dealing with some difficult philosophical and policy matters when we suggest use of prescribed fire in natural areas. Janet Johnson (1984) pointed out the paradoxes involved in a program that (1) has a goal of perpetuating systems that must change (short run) to stay the same (long run), and (2) in which our efforts to manage for perpetuation introduces human influences into natural systems although the purpose is to correct earlier human influences. Yet, human influences (fire suppression and others) have strongly impacted RNA ecosystems for more than 50 years. With large numbers of Americans showing strong interest in our public lands, we must manage all lands for whatever goals are decided upon. We cannot simply leave things alone and expect that will take care of RNA management.

It has been pointed out that trying to maintain dynamic biological complexes in any fixed condition is both futile and artificial (Johnson 1984). With the exceptions noted for RNA's established specifically to preserve examples of undisturbed and climax stage vegetation, the current trend in vegetation management would seem to be to try to allow natural processes to operate (or to simulate such processes), recognizing this is more likely to produce natural conditions than attempting the difficult task of holding dynamic processes static to maintain certain structural vegetative conditions.

In summary, then:

1. We need to be flexible in our plans for use of fire in RNA's. Depending upon whether we want to perpetuate a dynamic ecosystem through natural processes or whether we want to preserve existing "climax type" vegetation conditions, we may simulate natural fire processes through use of prescribed fires or we may attempt to suppress most fires with the least impact methods possible (the latter would be the exception in most ecosystems of the Intermountain West where fire--at shorter or longer intervals--is the rule.

2. Our overall task is to preserve (or perpetuate) both natural conditions and natural processes.

3. The specific goal is to maintain the ecological conditions for which each area was designated in as near natural a state as possible.

4. If fires ignited by lightning or Indians in lower elevations or vegetation types outside RNA's played a major role in igniting fires within the RNA, we need to consider use of prescribed fires to simulate such outside ignition sources.

5. We need to think through the role of fire and fire use at the time RNA's are being established. The location of the RNA may affect our ability to manage fire in the way most desirable.

6. More information is needed on specific fire history--the natural season, frequency, and intensity of fires in RNA's--to allow prescribed fires to better simulate the natural role of fire.

7. Concise planning documents are essential for each RNA to define how, when, why, and under what specific prescription fire will be used in the RNA. In developing the plan, give high priority to fire weather forecasts, burning indices, and fire history and vegetation patterns from the past.

8. Developing skilled prescribed burning personnel is an essential component to effective fire management programs in RNA's where use of RX fire is appropriate.

9. A reliable system for storing and retrieving fire treatment and effects information is a highly desirable addition to the fire management program of all RNA's.

PUBLICATIONS CITED

Johnson, Janet L. The role of fire in research natural areas. In: Lotan, J.E.; Kilgore, B. M.; Fischer, W. C.; Mutch, R., eds. Proceedings of the Symposium: Wilderness Fire, 1983 November 15-18; Missoula, MT. General Technical Report INT- . Ogden, UT: Intermountain Forest and Range Experiment Station; 1984 [in preparation].

Kilgore, B. M. What is "natural" in wilderness fire management? In: Lotan, J. E.; Kilgore, B. M.; Fischer, W. C.; Mutch, R., eds. Proceedings of the Symposium: Wilderness Fire, 1983 November 15-18; Missoula, MT General Technical Report INT- . Ogden, UT: Intermountain Forest and Range Experiment Station; 1984 [in preparation].

Wellner, C. Comments on the role of fire in research natural areas. In: Lotan, J. E.; Kilgore, B. M.; Fischer, W. C.; Mutch, R., eds. Proceedings of the Symposium: Wilderness Fire, 1983 November 15-18; Missoula, MT General Technical Report INT- . Ogden, UT: Intermountain Forest and Range Experiment Station; 1984 [in preparation].

FIRE IN RESEARCH NATURAL AREAS IN THE FOREST SERVICE

James E. Lotan

ABSTRACT

Research natural areas (RNA) in the USDA Forest Service are established to preserve a representative array of all significant natural ecosystems and their inherent processes. They are to be used to obtain information about natural system components, inherent processes, and comparisons with representative manipulated systems. Flexibility in protection and management is permitted to meet local situations, but manipulative practices are generally not used. The quandry is whether to strive for preserving natural vegetative conditions or to permit natural processes to function. Inasmuch as the role of fire varies in RNA's, flexibility is permitted. Management practices should be documented in the establishment report or in a management plan following establishment.

FOREST SERVICE RESEARCH NATURAL AREAS

Forest Service policy is similar to that stated by the Federal Committee on Ecological Reserves (1977). Forest Service RNA's are considered as part of the National System described by the committee. Two purposes for developing this system are:

1. To preserve a representative array of all significant natural ecosystems and their inherent processes as baseline areas . . .
2. To obtain . . . information about natural system components, inherent processes, and comparisons with . . . manipulative systems.

The National System in 1977 included almost 400 separate RNAs and covered over 4 million acres in 46 States. The Forest Service's contribution to this system includes 148 different RNA's covering nearly 178,000 acres (≅70 000 ha). They average 1,164 acres (≅470 ha).

FOREST SERVICE POLICY

The Forest Service Manual (FSM 4063) states that RNA's are limited to research, study, observations, monitoring, and educational activities that are nondestructive and nonmanipulative. Generally, it is Forest Service policy that RNA's be protected against activities that modify ecological processes. Logging and grazing is limited except for where their use is essential for maintenance of a specific vegetative type. Apparently, policy was written providing for flexibility depending upon the local situation.

Protection.--There is flexibility (ambiguity?) in policy regarding protection. The policy is that for each RNA there be specific management direction for protection from fire, insects, and disease. Yet in the very next sentence, "Maintenance of the natural processes within each area will be the prime consideration."

Fires within the area will be allowed to burn undisturbed unless they threaten persons or property outside the area, or the uniqueness of the RNA. Debris resulting from fires should not be cleaned up nor should any fire hazard reduction or reforestation be undertaken.

Vegetation Management.--Management practices are permitted that are necessary to preserve the vegetation for which the RNA was established. Practices such as grazing, control of animals, and prescribed burning are permitted with the proviso that only proven techniques be used. The intent is that the management practice must more closely preserve the vegetation and processes than would no management.

The underlying emphasis in RNA management is on preserving and protecting features of each area by controlling any disruptive use, encroachment, and development. Activities such as logging, grazing, burning, or restocking are prohibited unless the activity replaces natural processes and contributes to the protection and preservation of the designated feature. Such a practice is invoked only after thorough research and testing indicate that it adequately or favorably benefits the feature. In such an instance, a portion of the tract is left untreated as a control to justify the practice. Current policy clearly permits flexibility and interpretation.

THE PROBLEM

The problem of handling fire in research natural areas was recently discussed at the Wilderness Fire Symposium held in Missoula, November 15-18, 1983. Johnson (1984) and Wellner (1984) both did an excellent job of discussing the issues. Basically, we have the task of preserving both natural conditions and processes. Forest Service policy permits judgment regarding these goals. As Johnson (1984) stated: "These goals may not always be mutually compatible."

James E. Lotan is Supervisory Research Forester of the USDA Forest Service, Intermountain Forest and Range Experiment Station located at the Northern Forest Fire Laboratory in Missoula, Mont.

Fire is considered a natural process, but fire may also eliminate the very uniqueness for which the RNA was established.

Bonnicksen and Stone (1982) distinguished between these two goals and pointed out the inherent contradiction. Structural maintenance objectives are designed to maintain the structure and composition of vegetative communities. Process maintenance objectives preserve natural processes and accepting whatever structure and composition in the vegetative community that results in these processes.

Wellner's (1984) concerns are that most RNA's are established to preserve a condition (structural maintenance objective) and that undisturbed, advance stages of ecological development are becoming more rare. He cautions that fire be used only where essential to maintain conditions the RNA was established to protect.

RNA ecosystems vary from seral to advance stages of succession, and most certainly, no one overall fire management practice should prevail. There should be an equally vast array of fire treatments to meet the varied requirements of research natural areas. Where might natural, prescribed fires be used? What levels of protection are required? I believe that we must approach this subject with care, keeping in mind the role fire has historically played in each area and the purpose or particular feature of the area set aside.

A COURSE OF ACTION

The overall goal of RNA management should be to maintain the ecological conditions for which the area was designated in as near natural state as possible. The natural role of fire varies considerably in the vast array of ecosystems in the RNA system. Each area should be evaluated for the role of fire and fire hazard. Specific fire management objectives need to be established for both protection and use of fire. Ideally, this should be done at time of establishment and included in the establishment report. For those areas where the original establishment report did not address these issues there should be an additional management plan developed to include fire management concerns.

Fire is a powerful process and may be either harmful or beneficial. Fire management is the deliberate response to and use of fire based on sound plans that contain prescriptions to meet land management objectives for an area of interest (Fischer in preparation). These prescriptions need to be determined to meet the objectives of RNA's.

Current Forest Service policy is being rewritten. My comments here have been made regarding Forest Service Manual statements as they now stand.

Flexibility and judgment are now permitted and should be retained. The revision should retain this flexibility and permit professional judgment. I would like to see more direction to address fire problems more in keeping with recent changes in fire management policies. And to address the quandry of whether the RNA has been established to maintain structure and composition or processes. Fire is a powerful force and must be addressed.

PUBLICATIONS CITED

Bonnicksen, Thomas M.; Stone, Edward C. Managing vegetation within U.S. National Parks: a policy analysis. Environmental Management 6(2): 101-122; 1982.

Federal Committee on Ecological Reserves. A directory of Research Natural Areas on federal lands of the United States of America. U.S. Department of Agriculture, Forest Service; 1977, 280 p.

Fischer, William C. Wilderness fire management planning guide. General Technical Report INT___. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; [in preparation].

Johnson, Janet. The role of fire in research natural areas. In: Lotan, J. E.; Kilgore, B. M.; Fischer, W. C.; Mutch, R., eds. Proceedings of the Symposium: Wilderness Fire, 1983 November 15-18; Missoula, MT. General Technical Report INT- . Ogden, UT: U. S. Department of Agriculture, Forest Service; Intermountain Forest and Range Experiment Station; 1984 [in preparation].

Wellner, Charles A. Comments on the role of fire in research natural areas. In: Lotan, J. E.; Kilgore, B. M.; Fischer, W. C.; Mutch, R., eds. Proceedings of the Symposium: Wilderness Fire, 1983 November 15-18; Missoula, MT. General Technical Report INT- . Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1984 [in preparation].

FIRE AS A MANAGEMENT TOOL OF THE NATURE CONSERVANCY

Allen A. Steuter

INTRODUCTION

In 1962 Donald B. Lawrence and Frank D. Irving conducted a prescribed burn on the Helen Allison Savanna in Minnesota. This was the first prescribed burn on land owned by The Nature Conservancy and our interest in fire as a management tool has been developing since. At the present The Nature Conservancy owns approximately 700 preserves encompassing over 600,000 acres nationwide. In the Midwest Region alone there are 200 preserves with grassland or savanna communities in need of fire management. These preserves range in size from one acre to 54,000 acres and are often surrounded by intensively managed agricultural land. Many of the native plant communities and species of the Midwest Region are known to have developed under a relatively high historical fire frequency and require this disturbance to maintain vigor. Only the few largest preserves have permanent on-site staff. In this setting it becomes apparent that more than a superficial interest in prescribed burning is needed for efficient natural area management.

CURRENT DIRECTION

The policy of The Nature Conservancy is to use fire management when and where it contributes to the goal of maintaining species and communities targeted for preservation. Fire management actions are designed to maintain a high level of personal safety and contain the fire to predetermined areas for which specific management objectives have been established. Fire management represents a major allocation of time and physical resources. Consequently, the fire management effort is scaled to the endangerment of fire dependent species/communities, and to the urgency of instituting a fire program on a particular site.

Fire management on Conservancy preserves is focussed on prescribed burns resulting from intentional ignition. Because most preserves are small, unstaffed, and/or bordered by agricultural land, a policy of "let burn" within prescribed conditions for unintentional ignitions is not realistic. Specific objectives to be accomplished on a given site also require more managerial control than can be obtained by prescribed fire from unintentional ignition.

MANAGEMENT IMPLICATIONS

The Conservancy's fire management program relies on stewardship personnel taking an "active" role in assessing the ecological need for prescribed burning, allocating resources to meet these needs, and conducting the burn under prescribed conditions. An organizational commitment expressed in the form of policy/guidelines, training, planning coordination, and equipment is required before land stewards feel comfortable taking a prescribed burn out of the office and into the field. A key role is played by program administrators in encouraging and facilitating the safe and effective use of fire.

At present, fire management in the Conservancy is evolving toward a system of concise planning documents developed for each preserve by the person directly responsible for management. These plans are reviewed and must receive approval by regional stewardship staff who may call on outside expertise as needed. Fire safety is paramount However, a premium is placed on eliminating unnecessary duplication of effort if the required information exists in other preserve planning documents. The objective is to have a concise treatment of: (1) justification - why fire is needed and relative priority for maintaining target species; (2) site fire plan - rationale for timing and frequency of fire treatments; (3) prescribed burning plan - specific range of conditions under which the fire will be safe and effective; (4) fire summary report - a record of treatments, and notes on problems and recommendations; (5) fire effects documentation plan - priority and level of fire effects monitoring; and (6) fire effects report - species/community response information. The long-term effectiveness of this system relies on adequate review of planning documents, fire effects information from built-in monitoring and other technical research, and trained people to conduct the prescribed burning.

Allen A. Steuter is Preserve Manager and Research Specialist at the Niobrara Valley Preserve, The Nature Conservancy, RR1, Johnstown, Neb.

RECOMMENDATIONS

There is a need to increase the number of skilled prescribed burning personnel. Workshops are an important component of a training program. However, several years of actual management burn experience seem to be critical for producing the confidence necessary in on-site prescribed burn leadership. Developing this leadership corps of prescribed burning personnel appears to be the bottle-neck of many training programs. Stewardship personnel should be strongly encouraged to participate in scheduled burns, and fire leaders should make the most of management burns as educational opportunities for grooming additional burn leaders.

The technology and philosophies of the fire control industry should not be transferred to a prescribed burning program without a critical evaluation of their efficacy. The objectives and circumstances of most prescribed burns are radically different from wildfire situations. An efficient prescribed burning program will not be equivalent to an efficient fire control program.

A reliable system for storing and retrieving fire treatment and effects information will provide the necessary feedback for an increasingly effective prescribed burning program.

RESEARCH NATURAL AREAS AND FIRE IN THE NATIONAL PARK SYSTEM

James K. Agee

The research natural area concept is consistent with resources management policies of the National Park System. Research natural areas (RNA's) are tracts where "natural processes are allowed to dominate" (Franklin 1970) and where research and education are encouraged. Processes rather than objects are the focus of presentation efforts.

Current National Park Service management policies recognize fire as an important ecosystem process and one that, if feasible, should be allowed to play its natural role in ecosystems. Fire plans within national parks commonly use a combination of fire suppression and prescribed natural fire to meet resources management objectives. Prescribed fire is also used in situations where ecosystem restoration by fire is desirable or where the use of natural fires is not feasible, such as around developments, along boundaries.

The same types of policies are applicable in RNA's (Federal Committee on Ecological Reserves 1977): "Catastrophic natural events . . .{such as fire} . . . should ideally be allowed to take their course . . .", and prescribed fire is mentioned as a possible restorative tool.

In both national parks and RNA's, fire suppression is sometimes necessary. Human-caused wildfires will be suppressed in RNA's as elsewhere in parks. Low-impact methods of suppression are preferred, with the decision on use of strategy based on the overall least ecological impact to the RNA. If prescribed natural fires need suppression, firelines and retardants will be applied outside RNA's to the extent possible.

The general compatibility of purpose between RNA's and national parks suggests that few problems should arise as RNA's are nestled in parks. Such general compatibility should not imply that fire management problems do not exist; these problems can be summarized in several categories.

LOCATION AND SIZE

Although size is not a problem for RNA's in parks, location is very important. Many RNA's have been located near park boundaries or roads that provide good access but usually results in the RNA being in a fire exclusion buffer zone.

James K. Agee is Research Biologist/Associate Professor, National Park Service Cooperative Park Studies Unit, College of Forest Resources, University of Washington, Seattle.

COMPATIBILITY WITH RESEARCH OBJECTIVES

Although research is one objective of RNA's, not all research may be designed to include periodic disturbance by fire in the midst of a project. This is a bigger problem for short-term than long-term research. If prescribed fire is used, its "naturalness" may also be debated by researchers.

PRESCRIBED BURNING

Prescribed fire is allowed in all land-use categories in the National Park System, including RNA's. Mimicking the natural role of fire by planned ignitions, however, is a judgment call. Poor information bases make it difficult to know if burning is in the proper season and represents both the mean and variance of historical frequencies and intensities.

ABORIGINAL BURNING

In RNA's where the fire regime included frequent, low-intensity fire, Indian burning was often part of the available record. Should this be considered natural?

CONCLUSION

Research natural areas should be allowed to experience natural disturbances, including fire. Suppression actions should avoid RNA's whenever possible. Researchers should recognize the potential of fire in both planned facilities and design so as to avoid the need for enclaves within enclaves. In the placement of RNA's, the ability to manage fire should be one criterion in the establishment process.

PUBLICATIONS CITED

Franklin, J.F. Research Natural Areas in the Pacific Northwest. Mazama 52(13):30-34. 1970.

Federal Committee on Ecological Reserves. A Directory of Research Natural Areas on Federal Lands of the United States of America. Washington, D.C. USDA Forest Service. 1977. 280 pp.

PANEL ON GRAZING MANAGEMENT IN RESEARCH NATURAL AREAS: SUMMARY COMMENTS

Walter F. Mueggler

ABSTRACT: Grazing management on research natural areas (RNA's) is briefly discussed, including early objectives, current status, and future recommendations.

HISTORICAL PERSPECTIVE

Federal land management agencies have been concerned with the establishment of a research natural area (RNA) system within the United States for over 50 years. The present thrust, however, appears to date from about 1966 with the formation of a multi-agency Federal Committee on Research Natural Areas. In 1968 this committee in its directory of RNA's on Federal lands clarified desired objectives of the program and provided guidelines on use of the areas. Among the objectives were the preservation of examples of all significant natural ecosystems for comparison with those influenced by people, and preservation of gene pools for typical, rare, and endangered plants and animals. Management guides generally directed that natural processes be allowed to provide for continuance of the selected ecosystems.

In practice, emphasis has been placed on identifying suitable areas and officially establishing them within the RNA system. Once an area was within the system, lines were drawn and management directed toward "protection" from human influences. Little thought was given to the natural processes and dynamics of specific ecosystems or to the positive role of seemingly destructive agents, especially fire and grazing, in the maintenance of certain systems. As a consequence, management of RNA's typically became synonymous with protection rather than being a conscious attempt to recognize and provide for the continuance of those essential processes.

CURRENT APPROACH

The panelists at this symposium briefly reviewed the approach of The Nature Conservancy, the Forest Service, and the Fish and Wildlife Service toward grazing management in RNA's. There appears to be general concurrence regarding two major considerations related to grazing. First, candidate RNA's representing grassland ecosystems that have not had at least some livestock use are virtually nonexistent; thus, ecosystem representation must depend upon selections from those areas "least" altered by livestock grazing. Such decisions on relative alteration are highly subjective but necessary if we are to proceed with expanding grassland representation within the RNA system. Second, natural processes involved in the formation and maintenance of perhaps the majority of grassland ecosystems, particularly in the plains, included grazing by large native herbivores. Duplicating or mimicking this natural process may be essential to the preservation of such ecosystems.

The Nature Conservancy currently appears to be at the forefront in evaluating, planning, and implementing the type of direct management needed to maintain specific grassland ecosystems. Theirs is truly an aggressive approach to RNA management. Federal agencies are becoming increasingly sensitive to the need for active management, including purposeful grazing, to preserve examples of certain ecosystems; however, the lack of funds dedicated to the Federal RNA program have seriously constrained the intensive management that may be required to maintain such areas.

FUTURE DIRECTION

The thrust of the Federal RNA program has been to select and establish representative RNA's. This effort must continue if we are to achieve the goals of adequate ecosystem representation. However, the problems associated with RNA management must now be seriously addressed, especially by Federal agencies, or the integrity of the RNA program may be jeopardized.

Effective management consists of several important components. The uniqueness of each RNA must be recognized and, for each, specific management objectives established. A careful assessment of the natural processes controlling the welfare of each ecosystem is required (such as the role of fire or grazing by native herbivores). A management plan must be creatively formulated and implemented to permit these natural processes to continue, as well as to mimic essential processes no longer extant. An adequate system of monitoring is required to determine if the management objectives for a given area are being met and whether adjustments to the management plan are required.

Such active management of Federally administered RNA's does not appear possible under current funding levels. Secure, dedicated funding at a level commensurate with projected long-term RNA values will be required to permit the level of management needed to maintain the viability of the RNA system. Simply drawing a line around an area is not enough.

Walter F. Mueggler is Principal Plant Ecologist at the Intermountain Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture, Ogden, Utah.

GRAZING MANAGEMENT IN RESEARCH NATURAL AREAS

IN THE NORTHERN REGION OF THE FOREST SERVICE

Wendel J. Hann

ABSTRACT: This paper summarizes the policy of the Northern Region of the Forest Service relating to evaluation and management of grazing by big game and domestic livestock on research natural areas (RNA). Where livestock and/or wildlife grazing is a significant impact on a candidate or established RNA, an evaluation should be made concerning historical grazing impacts. RNA's should be selected that closely represent natural situations and managed to maintain those conditions. Livestock may be used for vegetation management to maintain the plant community as a natural type if the technique has been tested and will produce the predicted results.

INTRODUCTION

Policy concerning selection, establishment, and management of RNA's is outlined in the Forest Service Manual. The objective of the RNA program is to protect areas that typify natural situations relatively undisturbed by human activities. One of the primary disturbances is that associated with grazing of domestic livestock. Livestock grazing can cause significant changes in plant communities when compared to the natural situation. Human influence in displacing wildlife from their native habitats and concentrating their use in areas that did not naturally support heavy use has been an additional impact.

FOREST SERVICE POLICY CONCERNING GRAZING IN RESEARCH NATURAL AREAS

The basic philosophy for RNA establishment and management is to "promote and protect natural diversity in all of its forms." This is done by establishing and protecting areas that typify important and unique conditions of forest, shrubland, grassland, alpine, aquatic, geologic types, or other natural situations. Policy is specific in stating that RNA's are for nonmanipulative research, observation, and study. When selecting and establishing RNA's, a basic guideline is that the area should not show evidence of human disturbance for at least the past 50 years. However, if for a given situation there are no sites that meet this criterion, then the least disturbed area may be selected. Candidate RNAs should be evaluated relative to impacts from grazing by both wildlife and domestic livestock based on the following criteria:

1. Historical use by native herbivores should be documented. Both the recent history of use since modern settlement and the history of plant species development and herbivore use through geologic time should be considered.
2. The present conditions should be compared to what is thought to have been present prior to the influence of modern settlers.
3. Availability of areas representative of different ecosystems should be considered. If few representative areas are available, then an area that is somewhat disturbed may have to be accepted.

Management decisions related to RNA's may present a more difficult problem than that of selection and establishment. Forest Service policy is to protect "against activities which directly or indirectly modify ecological processes if the area is to be of value" and further restricts livestock grazing "to those areas where their use is essential for the maintenance of a specific vegetative type." The grazing system that is used should be proven such that its use will provide a closer approximation to the natural situation than without grazing.

SUMMARY

Grazing is a natural process in many of the plant communities in the Northern Region. The major ecosystems for which grazing should be considered part of the natural process are the shrub- and grass-steppe. However, grazing has also been an important part of the development of open forests, savannah forest-steppe, subalpine and alpine openings, and wetland shrub and herbaceous types. Forest Service policy allows for use of livestock to manipulate natural vegetation if a tested management system can be implemented to produce plant communities similar to those that would exist naturally.

Wendel J. Hann, Regional Ecologist, USDA Forest Service, Northern Region, Missoula, Mont.

NATURAL AREA MANAGEMENT

OF MONTANA NATIONAL WILDLIFE REFUGES

Barnet W. Schranck

INTRODUCTION

Research natural areas are of special interest not only to scientists but to a wide variety of people concerned with the welfare of various ecosystems. The purpose of this paper is twofold: first, to discuss the management of officially designated research natural areas (RNA) on national wildlife refuges (NWR) in Montana; secondly, to provide a broad overview of grazing management on NWR's, with special reference to the Charles M. Russell (CMR) NWR.

RESEARCH NATURAL AREA

The U.S. Fish and Wildlife Service, along with other agencies, is committed to the RNA program as initially developed in 1966 with the Federal Committee on Ecological Reserves. As a result of the thrust to set natural areas aside, 174 RNA's on 82 NWR's involving 1,228,101 acres were established nationally. In Montana, the Service is responsible for 10 RNA's: CMR - , Benton Lake NWR - 1, Medicine Lake NWR - 4, and Red Rock Lakes NWR - 1. Approximately 1,457 acres are involved, and the areas vary in size from 15 to 392 acres. Seven of the 10 areas are islands. According to the 1977 Directory of RNA's on Federal land, 30 areas covering 71,580 acres located in Montana are managed by a variety of Federal agencies. The Service is responsible for only 2 percent of the acreage.

Since the establishment of these areas, no grazing, haying or burning has been done; nor do we anticipate any in the near future. Also, there has been no specific use of the RNA's by the scientific community.

The Service does have guidelines on the management of RNA's. Generally, an area is allowed to advance toward a climax. However, vegetation may be maintained at a desired seral stage when the primary purpose of the area is dependent on a specific stage. Grazing, haying, and burning may be done only with the development of an approved plan.

NWR SYSTEM AND LAND MANAGEMENT

One of the goals of the Service is "to preserve natural diversity and abundance of fauna and flora on refuge lands." This is certainly in accordance with the objectives of the Federal Committee on Ecological Resources, originally dealing with RNA's. Grazing, haying, and burning of vegetation are considered tools to manipulate habitat for the benefit of wildlife. It is important to remember that NWR's are not multipurpose areas. They are set aside for wildlife use, and other uses are secondary. Management actions are governed by the NWRS Administrative Act of 1966, which basically states that all activities must be compatible with the purpose for which the land was acquired.

CMR GRAZING PROGRAM

The development of the CMR land management program presents an interesting story. Executive Order (E.O.) 7509 created the Fort Peck Game Range in 1937 and, since 1976, it has been known as the Charles M. Russell National Wildlife Refuge. Initially, the area was jointly managed by the Bureau of Land Management (BLM) and Fish and Wildlife Service for 40 years under the Taylor Grazing Act. Court action in 1975 stated that BLM was not giving adequate consideration to wildlife and required an environmental impact statement (EIS) for developing a master plan. Various types of litigation followed, but on October 13, 1983, the U.S. Ninth Circuit Court of Appeals ruled that: (1) wildlife has priority in access to forage in accordance with E.O. 7509; (2) beyond those limits, wildlife and livestock have equal priority; and (3) CMR is to be administered under the NWR's Administrative Act of 1966. The draft EIS will be available for public review in 1984.

The Refuge Mission is ". . .to preserve, restore, and manage in a generally natural setting a portion of the nationally significant Missouri River breaks. . . optimize wildlife resources and compatible human benefits. . ." This, too, is in line with the concept of RNA's.

The planning process used to enable the Service to meet this mission consisted of four steps. The first step involved the completion of range site and condition surveys to determine available animal use months (AUM's). This was done in 1978 using the Soil Conservation Service's (SCS) National Range Handbook. Step two involved the development of a slope/water matrix based on livestock observations in relation to slope and distance to water. For example, AUM's associated with 0-10 percent slopes and 0-0.25 mile from water were assigned to livestock. AUM's associated with 50 percent and greater slopes were assigned to wildlife. AUM's beyond 0.5 mile on steep land and 2.5 miles on level land were also assigned to wildlife. Step three took in consideration erosion potentials, and livestock AUM's were reduced accordingly. The fourth step involved the evaluation of various sites as to the

Barnet W. Schrank is Refuge Supervisor for Montana and Wyoming at the U.S. Fish and Wildlife Service Regional Office, Denver, Colo.

documented wildlife value. AUM's were assigned to wildlife in these cases.

It should be pointed out that this procedure was used for development of the proposed action in the DEIS, and as such, it is not final. A record of decision on the management of CMR will probably be issued late this year. In addition, a number of items are still under litigation, which must limit my comments.

In any event, once the broad management plan is in place, specific management plans covering the 67 allotments will be developed in cooperation with the 92 permittees and landowners.

The grazing program will be monitored and adjusted as needed, using information obtained from (1) permanent photographic sites, (2) Daubenmire transects, (3) Robel transects, and (4) exclosures.

SUMMARY

Research natural areas managed by the Service in Montana are basically unchanged since their establishment, and none are currently grazed. Grazing at CMR is currently being addressed in a draft EIS, and based on the court decision, management will be directed toward wildlife. This will result in a more natural ecosystem.

GRAZING MANAGEMENT IN THE NATURE CONSERVANCY

Mark Heitlinger and Allen A. Steuter

NTRODUCTION

ne goal of The Nature Conservancy is to preserve atural diversity through securing habitat for ne most endangered species and maintaining re- resentative examples of natural communities. In ost grasslands large hooved animals were an impor- ant evolutionary and ecological force for millions f years. Grazing modifies vegetation height and ensity. This strongly affects habitat quality. ifferential responses to grazing are observed in irds, mammals, insects, and microbial activity. iet selection by herbivores influences vegetation omposition since plant species decrease, increase, r invade with grazing. Different grazing species ary in their forage preferences and other as- ects of grazing behavior. To plants, critical actors are the severity, frequency, and season- lity of defoliation. Management can modify in- ate grazing tendencies through regulating tocking density, fencing and herding, burning, lacement of minerals and water, and other means. ne-herd multipasture systems provide the most ontrol over grazer-plant interactions. Many uthorities believe the type of discontinuous orage removal provided by rotational grazing irrors what occurred before European culture nd domesticated animals invaded rangelands. In arge wilderness areas, native ungulates may unction much as they did prior to white settle- ent. Even in these situations it is difficult o provide unrestricted opportunities for migra- ion and predator-prey interactions. Grazing on elatively small Nature Conservancy preserves annot be justified on the grounds of establish- ng a complete grassland ecosystem. We use razing as a tool to mold admittedly incomplete ystems toward a structure that we infer to be imilar to that of aboriginal times. Grazing is tool to create preferred habitat for high prior- ty species. Grazing may also be used when we are orced by constraints to utilize less than optimal anagement treatments. For example, high stocking ensity, short duration grazing may substitute for ire where burning is not feasible. Certain razing systems aid in the recovery of abused rasslands.

RRENT DIRECTIONS

urrent directions may be summarized by two examples. At Cross Ranch (ND) we have plans to establish a 1,000-acre bison pasture in which fire is used to induce rotational grazing. We believe herds of native bison in this region grazed some areas severely in a deferred or rest rotation cycle. There was probably also chronic light grazing by solitary animals and small local herds. This inferred grazing regime is to be simulated by burning four 20-acre areas each year on a 10-year fire rotation. We expect the bison to graze heavily on the freshly burned areas and lightly to moderately on the rest of the pasture. Because burning is rotated, heavy grazing should last only about 1 or 2 years every 10 years. Approximately 20 percent of the pasture will be permanently unburned and open to grazing. Cattle grazing and fire-only management elsewhere on the preserve also provide comparison areas.

At the S.H. Ordway Prairie (SD) we have established several different fire, grazing, and combination treatments. Objectives include reducing the exotic Kentucky bluegrass, producing pasture-to-pasture variation in vegetation structure, and studying the role of perturbation in the northern mixed prairie. In part of the preserve cattle graze for three 6-week periods in each of three pastures. The grazing period is rotated so a pasture is grazed during each grazing period only once in 3 years. In another three pastures the system is duplicated except that the period of grazing is not rotated. Other comparisons are provided by continuous cattle and continuous bison grazing during the same 18-week period, dormant season bison grazing, and fire-only management including several different fire frequencies. The season-long grazed pastures and one of the deferred rotation pastures are burned once in 3 years.

IMPLICATIONS

Grazing animals, even if native species, do not insure duplication of the selectivity, severity, frequency, and seasonality of defoliation as it occurred in aboriginal times. There are special problems with grazing including uneven distribution, edge effects along fences, and weed seed dispersal. Grazing prescriptions must be clearly defined and enforced. Herds of appropriate size, kind, and class of animal must be located. Grazing may be interpreted by some as a violation of corporate farming laws and a disqualification for property tax exemption. Animal control is parti-

ark Heitlinger is Director of Ecological Manage- ent for the Midwest Region of The Nature Conser- ancy, 328 E. Hennepin Ave., Minneapolis, Minn. llen A. Steuter is Preserve Manager and Research pecialist at the Niobrara Valley Preserve, The ature Conservancy, RR1, Johnstown, Neb.

cularly difficult on small, unstaffed preserves. The desired background information is often lacking and grazing effects are difficult to study.

RECOMMENDATIONS

Despite these problems, The Nature Conservancy uses grazing to achieve grassland preserve goals. The process involves making informed inferences about the native grazing regime; carefully defining preserve objectives and relating them to forage removal; considering constraints; planning the grazing units, schedules, species, and stocking limitations; developing fences and other facilities as needed; administering arrangements and monitoring compliance; conducting ecological monitoring and evaluation. We recommend using native grazing species when possible, including fire in the treatment plan, and maintaining reference areas for comparative purposes.

Monitoring should be used to assess achievement of preserve goals. It is unreasonable, however, to defer management until the grazing effects are understood in minute detail. We must have a degree of faith in our ability to infer ecosystem structure and function and to use monitoring as an early warning system to detect serious problems.

Numerous grazing systems have been described. There is a temptation to begin the planning process by selecting from this menu of tools. It is preferable to begin by identifying the ecological objectives to which grazing may contribute and customizing the tool to do the job.

Section 4. Symposium Conclusions and Poster Session Abstracts

BASELINE MONITORING AND MANAGEMENT OF RNA'S:

SYMPOSIUM CONCLUSIONS

Richard G. Krebill, Janet L. Johnson, and Robert D. Pfister

Since the start of the research natural area (RNA) concept in the 1920's, proponents have placed prime emphasis on initial establishment of areas to provide an extensive network of undisturbed sites for future research and education. Progress has been substantial with some 440 areas now activated, and perhaps an equal number under consideration for establishment within the next decade. Generalized policies for management of research natural areas have developed; but in practice our management often neglects such factors as the natural role of fire and of ungulate grazing. We have done surprisingly little to develop baseline information useful to determining stability of inherent ecosystems. With concerns for these subjects in mind, this symposium was formulated to discuss and provide new insight into baseline monitoring, fire management, and grazing management for research natural areas.

The opening keynote comments of Jerry Franklin chastised the scientific community for our poor record of scientific use and documentation of activities on research natural areas. He pointed to the danger of "use it or lose it," and offered some helpful suggestions to increase the scientific viability of research natural areas. Jerry concluded his comments with the hope that this symposium would ". . . help stimulate baseline monitoring and research in the outstanding system of natural areas that we are creating. . . ."

Baseline monitoring was viewed in this symposium as an important activity to document changes that might otherwise be overlooked. Effects of climatic shifts on ecological succession might be detected. Monitoring can provide early alerts to environmental impacts such as toxic air pollutants. Quantifying the status of natural ecosystems serves as baseline information needed to compare changes on manipulated sites of similar ecosystems. In this way, research natural areas are somewhat akin to range management's grazing exclosures, except that because of their larger size and management, they need not suffer confounding edge effects.

Although monitoring is important, several participants pointed out that research natural areas also have a large and growing utility for future research as the presence of undisturbed areas becomes a rare part of the nation's lands. A case in point involves the northern Idaho forest habitat type revision study, which depended on plot locations within mature, undisturbed stands. The search for suitable sites was minimized by going directly to proposed and established RNA's in northern Idaho. With time, research on RNA's will benefit from the synergistic effects of focusing a myriad of studies on special sites.

There are many components of the ecosystem worthy of monitoring. Our interest might be with the cryptogams, whereas others are concerned with vascular plants, animals, aquatic microorganisms, or the soil, water, and air resources. Still others are more interested in processes rather than components of ecosystems. But monitoring is expensive and time consuming, so how might it best be done? Symposium participants provided the following advice: First, for each research natural area, thoughtfully define objectives. Next, identify what is to be regularly monitored giving priority to the utility of achieving objectives. (Other interests should be encouraged to perform studies in research natural areas as their findings may in fact become bases to our unpredicted future.) Sampling designs should be simple and repeatable by others and over long periods of time. Randomization and replication are paramount attributes of any valid statistical design. Proper planning of monitoring activities cannot be overstressed, and consultation with a statistician is highly recommended. Statisticians may advise use of progressive approaches of data analysis such as the "cumulative sum" method, as well as the standard techniques. Consider the possibility of coordinating an interdisciplinary team to sample various components and processes within any RNA. When performing field studies, be sure data collectors are well trained and periodically check for conformance to standards. Archive the data so that it is secure and readily available to yourself and to others for perpetuity. Publications are time-proven in that respect, and the computer age offers attractive possibilities. Be cost-effective, as the monitoring job is immense, and resources to physically tackle the job are small.

Our attention also turned productively toward the role and management of fire and grazing on research natural areas. Again, symposium participants stressed the need for declaring objectives on a site-specific basis. Natural disturbances such as fires and grazing by native ungulates have had a major role in shaping the structure and composition of most ecosystems represented within

Richard G. Krebill is Assistant Station Director, Research for the Intermountain Forest and Range Experiment Station, USDA Forest Service, Missoula, Mont. Janet L. Johnson is Research Natural Area Coordinator for the Northern Region, USDA Forest Service, Missoula, Mont. Robert D. Pfister is Director of the Mission Oriented Research Program, School of Forestry, University of Montana, Missoula, Mont.

esearch natural areas. If these areas are to emain "natural," shouldn't fire and grazing be etained? We agreed, for the most part, that our olicies and their implementation must be lexible. The relative small size of research atural areas often necessitates active management through reintroduction of ecological rocesses to stimulate natural conditions. For reas where the objective is to maintain ld-growth forests, it may be appropriate to xclude fire for centuries. But where we're rying to maintain grasslands, we may need to rescribe annual fires and encourage grazing to ssure an appropriate vegetative composition. ative ungulates might be favored for grazing, ut some participants suggest that domestic livestock grazing could be used as a practical alternative if applied under good management. The hought that fire and grazing might best be used n concert on some sites, though logical, was an mportant new thought to the symposium organizers.

n her evening presentation entitled "Across the orthern Region--from cedar groves to tall grass prairies," Janet Johnson provided a look at the beauty and the immense intrinsic values of research natural areas. She also pointed out that it is dedicated people such as you who make research natural areas possible, useful, and even fun.

We found through these many presentations, from some outstanding poster displays, and by numerous person-to-person conversations, that there are many examples of extraordinarily good stewardship on research natural areas and that baseline data are being collected in quite a few locations. Surely, as one participant stated, "We've come a long way," and we are progressing. And most of all, we found such a high degree of dedication and spirit of cooperation among participants, that we're convinced that research natural areas are here to stay. Yes, Jerry Franklin, we met your hopes for a successful symposium. Challenges were presented, needs were stated, and ideas were explored. Implementation of these ideas through diligence and perseverance can lead the way to a fruitful era of baseline monitoring and research in our natural areas.

ROCKY MOUNTAIN FRONT GRIZZLY BEAR MONITORING AND INVESTIGATION

Keith Aune and Tom Stivers

From 1977 to 1983, grizzly bear research was conducted along the east slope of the Rocky Mountains, an area that includes The Nature Conservancy's Pine Butte Preserve. The objectives of the study include (1) to delineate and define essential habitat and important use areas within the study area, (2) to determine impacts associated with gas and oil exploration, and other human activities, and (3) make recommendations to protect and maintain grizzly populations and habitat.

Keith Aune and Tom Stivers are Fish and Wildlife Biologists. Report prepared for The Nature Conservancy, P.O. Box 258, Helena, Mont.

MONTANA'S RIPARIAN AND WETLAND IMPROVEMENT PROGRAM

Paul Brouha

A slide tape has been prepared with the intent of introducing the concepts of riparian and wetland values to a variety of nontechnical audiences. The potential values lost by improper management of riparian and wetland areas are featured. The concept of a riparian and wetland tax incentive and tax credit program to foster proper management of these is introduced.

Paul Brouha is Fisheries Program Manager for the Northern Region, USDA Forest Service, Missoula, Mont

FIFTY YEARS OF SUCCESSION IN YELLOWSTONE NATIONAL PARK MEASURED ON PERMANENT PLOTS

Don G. Despain

As part of a general vegetation survey of the park, four permanent plots were established in 1935 to document plant succession in Yellowstone's forests. Each plot was 1 chain (66 ft) square and all living trees, seedlings, and saplings were located on a plot map. Record was made of species, height, and, for trees over 1.5 dbh, diameter and growth increment during the first 10 years and last 20 years. One of the plots has since been destroyed by construction and one has been lost, but the other two were remeasured in 1957 and again in 1976.

One of the remaining plots is in a Douglas-fir forest (Pseudotsuga menziesii/Symphoricarpos albus HT) in the montane zone at 6,270 ft elevation. The other is in a subalpine, old-growth, lodgepole pine stand (Abies lasiocarpa/Thalictrum occidentale HT) at 8,280 ft elevation.

The most striking result of the remeasurement is the lack of change that has occurred in the intervening years. In the lower stand, only five trees have died, all subordinates. None have become established. Basal area increased from 16 to 20 sq. ft. In the upper stand, four trees and five saplings died. Seedlings and saplings increased by 97 individuals. Basal area increased from 22.5 to 25 sq. ft. These results emphasize that succession is a very slow process in Yellowstone's cool, dry environment.

Don G. Despain is Research Biologist at Yellowstone National Park, Mammoth, Wyo.

METHODS FOR MEASURING SOIL DETERIORATION

William C. Fanning

Soil deterioration data of the Intermountain rangeland ecosystem has historically been difficult for the Bureau of Land Management to acquire due to budget limitations and the ease of using subjective techniques. The BLM's Butte District, Butte, Montana, is attempting to quantify soil deterioration to determine long-range erosion and compaction trends using objective methods. The methods include channel geometry of gullies and erosion point frame for erosion and bulk density (clod method) and the soil penetrometer for compaction.

William C. Fanning is District Soil Scientist, Butte District, USDI Bureau of Land Management, Butte, Mont.

RESEARCH NATURAL AREAS IN IDAHO

Douglass M. Henderson and Charles A. Wellner

hirty-two research natural areas or equivalents ave been established in Idaho. These are istributed among agencies as follows: USDA orest Service - 20 RNA's and 2 botanical areas, SDI Bureau of Land Management - 1 RNA, USDI ational Park Service - 1 RNA, Idaho Department f Parks and Recreation - 3 RNA's, Idaho State niversity - 1 RNA, The Nature Conservancy - Nature Preserves. Thirteen of these established reas were the result of work by the Idaho Natural reas Coordinating Committee.

he Idaho Natural Areas Coordinating Committee, a olunteer organization of interested citizens, was rganized in 1974 to further the selection and esignation of research natural areas. The ommittee is composed of six technical committees: orests, grasslands and shrublands, alpine, aquatic ituations, rare plants, and rare animals. The ommittee cataloged and classified natural diversity n Idaho by geomorphic provinces and developed a lan for selection of candidate research natural reas. It cooperated with the Forest Service and he Bureau of Land Management in selection of andidate areas and has recommended candidate areas o all National Forests and Bureau of Land Manage-ent Districts in Idaho. Candidate National Forest reas total 100 and Bureau of Land Management areas otal 35.

embers of the Idaho Committee have prepared everal publications on natural diversity and esearch natural areas in Idaho.

---

uglass M. Henderson is Associate Professor of otany and Director of the Herbarium at the niversity of Idaho, Moscow. Charles A. Wellner JSDA Forest Service, retired) is Chairman of laho Natural Areas Coordinating Committee at oscow.

PRESCRIBED BURNING AND WOOD HARVESTING IN THE EAT BASIN: IMPLICATIONS FOR PINYON-JUNIPER RNA's

Susan Koniak and Richard L. Everett

nyon-juniper woodlands decrease in understory versity and cover with increasing tree minance. To maintain a variety of successional ages within pinyon-juniper research natural eas, prescribed burning and wood harvesting may used in lieu of natural perturbations. In the eat Basin, chronosequences for species following wildfire and early successional models for prescribed burns and tree harvesting have been developed that can aid in predicting plant response.

Pretreatment vegetation, aspect, elevation, soil, seed reserves, post-treatment precipitation, and slash disposal after harvesting are the primary determinants of post-treatment vegetal response. Understory species generally retain or augment their pretreatment levels of occurrence and cover after burning or harvesting. Shrubs that regenerate by seed are reduced after burning, but return to preburn levels within 5 to 10 years. Few species occur on postburn or harvest stands that are not evident in mature woodlands. If pretreatment vegetation is not known, previously determined species preference for aspect and elevation can help in predicting post-treatment response. Low precipitation following burning tends to increase the annual component of the vegetation. Burning slash following harvesting can reduce plant response. Lop and shatter appears to be the best slash treatment for enhancing postharvest vegetal response.

Post-treatment succession in pinyon-juniper woodlands relies on the sequential dominance of the site by understory species present immediately after disturbance based mainly on their longevity or life cycles. When tree species are eliminated from a site, reentry of the species into the plant community depends upon perennial nurse plants associated with late successional stages. The successional cycle following harvesting is generally shorter that the cycle following fire. The remnant understory plants provide a seed source that can rapidly replenish the understory vegetation. Young trees left on the site quickly dominate the area.

The selection of management alternatives in pinyon-juniper woodlands should be based on expected vegetal response and economic concerns. Prescribed burning has the highest potential for successful ignition, good understory response, and least loss of wood products in the ecotonal areas between pinyon-juniper and sagebrush. Currently, wood harvesting is only economically feasible in accessible, fully stocked stands. Selection of sites with desirable understory species followed by proper slash disposal will facilitate the return of high quality vegetation on the site after harvesting. To prevent waste of wood products, fully stocked stands should only be burned if harvesting is not feasible. High elevation sites and midelevation north and east slopes would produce the most desirable postburning vegetal response.

Susan Koniak and Richard L. Everett are Range Scientists, Intermountain Forest and Range Experiment Station, USDA Forest Service, Ogden, Utah, located at Reno, Nev.

MONITORING SOIL CLIMATE

Al Martinson, Bill Basko, Lou Kuennen, and Marci Gerhardt

Soil moisture and temperature have been monitored on the Flathead National Forest since November 1979. These data are used to classify soils, to aid in making silvicultural decisions and to determine when soils are least susceptible to compaction. Soil moisture trends appear to be related to precipitation patterns. In winter when snow covers the ground, and in spring during snow-melt and spring rains, soils are approaching field moisture capacity. In late June or July soils begin to dry out. Soils reach their driest moisture level between August and October. Fall rains, which come between October and December, bring soil moisture up to field capacity. Soil temperatures in winter are seldom below freezing. It appears that snowpacks insulate the soil enough to prevent freezing.

Al Martinson and Bill Basko are Soil Scientists, Flathead National Forest, USDA Forest Service, Kalispell, Mont. Lou Kuennen and Marci Gerhardt are Soil Scientists, Kootenai National Forest, USDA Forest Service, Libby, Mont.

WATER QUALITY MONITORING ON THE LOLO NATIONAL FOREST

Arne E. Rosquist

National Forests are required to protect and maintain water quality for fish habitat, domestic consumption, recreation, and other downstream uses. Instream monitoring of water quality is one way of assessing how well this objective is met. Project monitoring on the Lolo National Forest is conducted primarily to assess the effects of road construction and timber harvest on the total sediment load of Forest streams. Other activities on National Forest lands also have the potential to alter water quality. Water monitoring techniques employed and factors measured are determined by both type of activity and water use.

Arne E. Rosquist is a Forest Hydrologist on the Lolo National Forest, Missoula, Mont.

STATE OF WASHINGTON NATURAL AREA PRESERVE SYSTEM: MANAGEMENT AND MONITORING

Mark V. Sheehan and S. Reid Schuller

Over 30 state and private natural area preserves (NAP) comprise the Natural Area Preserve System in Washington. They are set aside to serve as gene pool reservoirs for native plant and animal species, especially rare, threatened or endangered organisms; to provide outdoor laboratories for scientific research and education; and to serve as baselines to be compared with similar managed ecosystems.

NAP's are managed by the Department of Natural Resources, Washington State University, University of Washington, and the Nature Conservancy. The management of NAP's is guided by a general policy that states: (1) natural ecological processes should be allowed to operate unimpeded by human encroachment or intervention; (2) each area will be managed to maintain the feature(s) and governing natural processes for which it was designated; and (3) NAP's are to be used primarily for scientific and educational purposes.

The acceptable uses of an NAP are guided by a management plan. This plan lists the significant features within an NAP, management needed to maintain or restore each feature, and management issues that may require future attention, such as the control of exotic species.

A monitoring program has been established for the NAP system. Its purposes include the identification of factors affecting preserve integrity, the tracking of community structure and composition, and the tracking of shifts in selected species populations. Baseline data such as provided by floral and faunal surveys, permanent vegetation plots, permanent photopoints, mapping of significant features and censusing of selected species are collected. An ongoing inventory is maintained as part of the monitoring effort.

Mark V. Sheehan is Program Manager of the Washington Natural Heritage Program, Department of Natural Resources, Olympia, Wash.
S. Reid Schuller is Plant Ecologist at the Washington Natural Heritage Program.

*U.S. GOVERNMENT PRINTING OFFICE: 1984-0-576-040/10500

Johnson, Janet L.; Franklin, Jerry F.; Krebill, Richard G., coordinators. Research natural areas: baseline monitoring and management: proceedings of a symposium; 1984 March 21; Missoula, MT. General Technical Report INT-173. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1984. 84 p.

More than 400 research natural areas have been established in the United States, and a similar number are under consideration as additions. To fulfill their research and educational expectations, these areas require both adequate baseline information and good management to perpetuate their naturalness. These proceedings include papers by prominent scientists of the Northwest who address many aspects of the planning, design, sampling, analysis, and archiving of data needed for effective monitoring for a wide range of biological systems. Also included are case examples and papers dealing with the special considerations necessary for grazing and fire management in research natural areas.

KEYWORDS: research natural areas, natural areas, baseline monitoring, monitoring, fire management, grazing.

The Intermountain Station, headquartered in Ogden, Utah, is one of eight regional experiment stations charged with providing scientific knowledge to help resource managers meet human needs and protect forest and range ecosystems.

The Intermountain Station includes the States of Montana, Idaho, Utah, Nevada, and western Wyoming. About 231 million acres, or 85 percent, of the land area in the Station territory are classified as forest and rangeland. These lands include grasslands, deserts, shrublands, alpine areas, and well-stocked forests. They supply fiber for forest industries; minerals for energy and industrial development; and water for domestic and industrial consumption. They also provide recreation opportunities for millions of visitors each year.

Field programs and research work units of the Station are maintained in:

Boise, Idaho

Bozeman, Montana (in cooperation with Montana State University)

Logan, Utah (in cooperation with Utah State University)

Missoula, Montana (in cooperation with the University of Montana)

Moscow, Idaho (in cooperation with the University of Idaho)

Provo, Utah (in cooperation with Brigham Young University)

Reno, Nevada (in cooperation with the University of Nevada)

United States
Department of
Agriculture

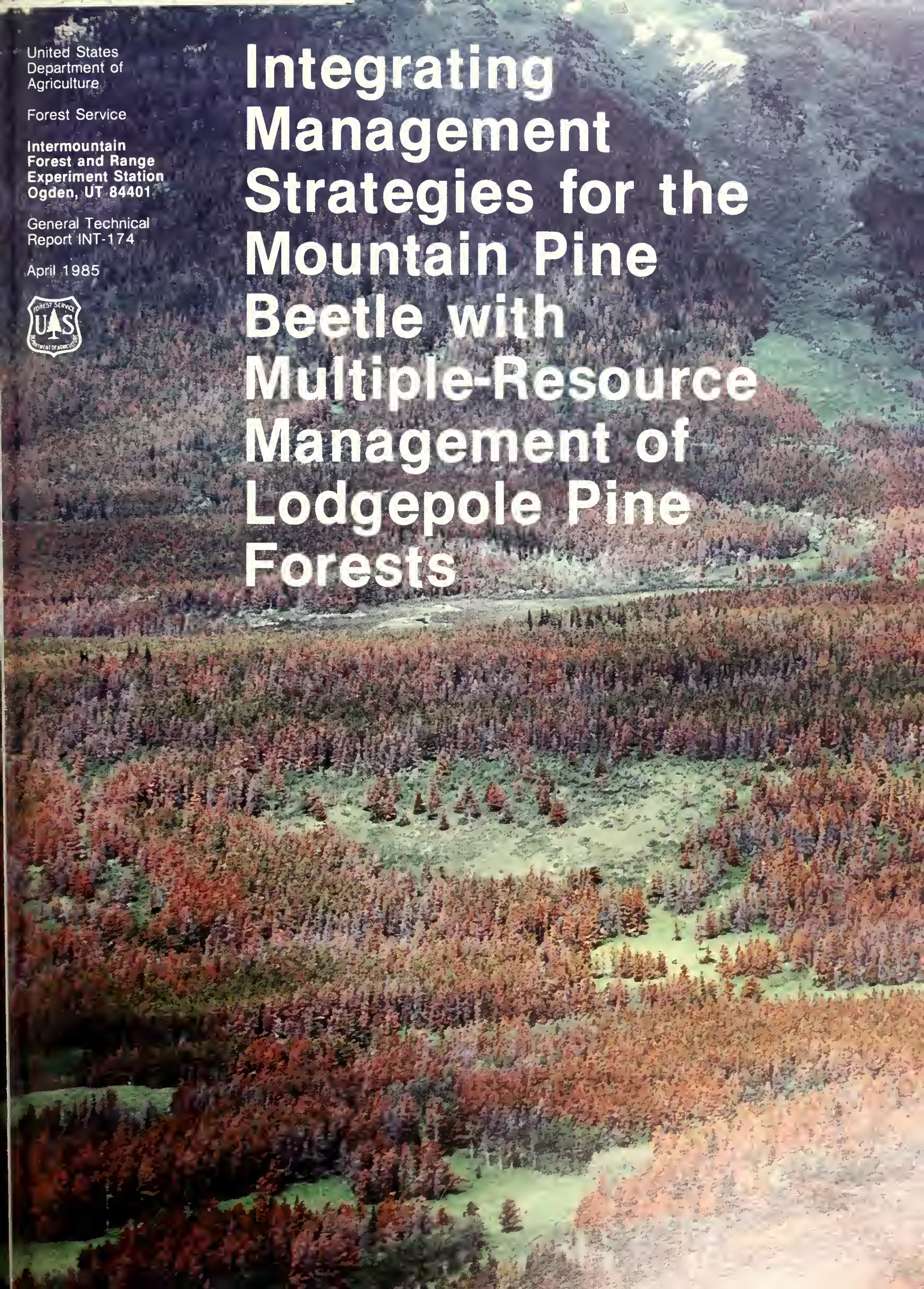
Forest Service

**Intermountain
Forest and Range
Experiment Station
Ogden, UT 84401**

General Technical
Report INT-174

April 1985

Integrating Management Strategies for the Mountain Pine Beetle with Multiple-Resource Management of Lodgepole Pine Forests



ACKNOWLEDGMENTS

These guidelines are the result of the efforts of many people. We are grateful for their assistance.

Robert Eder and Ralph Johnson, Northern Region, Forest Service, U.S. Department of Agriculture, developed the computer programs for summarizing the forest inventory data bases of the Gallatin and Flathead National Forests. Randall Gay and Fred Hodgboom, timber planners of those respective Forests, provided guidance on expanding sample acreages of habitat types to the overall forests.

Certain sections of the paper are written or coauthored by specialists in those subject areas and are so indicated in the table of contents.

Critical review of the manuscript was provided by L. Safranyik, R. Naumann, O. Engelby, D. Holland, M. Ollieu, G. Amman, K. Evans, G. Wilson, R. Byars, W. Burbridge, R. Pfister, and R. Mutch.

Cover photo: Unmanaged lodgepole pine stands in Glacier National Park have suffered extensive beetle damage during the past 10 years. Restrictions on preventive management limit efforts to circumvent such damage; the typical result is similar severe damage in adjacent forested areas.

Integrating Management Strategies for the Mountain Pine Beetle with Multiple-Resource Management of Lodgepole Pine Forests

EDITORS:
MARK D. McGREGOR, Entomologist, Cooperative Forestry and Pest Management, State and Private Forestry, Northern Region, Forest Service, U.S. Department of Agriculture, Missoula, MT.
DENNIS M. COLE, Research Silviculturist, Intermountain Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture, Bozeman, MT.

RESEARCH SUMMARY

Guidelines are presented to assist forest managers in integrating pest management techniques for the mountain pine beetle (*Dendroctonus ponderosae* Hopk.) with other resource considerations in the process of planning and executing balanced resource management of lodgepole pine (*Pinus contorta* var. *latifolia*) forests. The guidelines summarize published and unpublished technical information and recent research on the ecological interaction of pest and host and present visual and classification criteria and methods for recognizing and summarizing occurrence and susceptibility status of lodgepole pine stands according to habitat types and successional roles and important resource considerations associated with them. Information is summarized for appropriate silvicultural systems and for practices that address significant resource concerns of commercial and noncommercial forest land designations and wilderness and other special administrative areas. A data acquisition, data analysis, and decision framework is presented for integrating management of mountain pine beetle populations with multiple resource management of lodgepole pine forests.

CONTENTS

INTRODUCTION

The mountain pine beetle (*Dendroctonus ponderosae* Hopk.) is a native bark beetle whose depredations affect management of the lodgepole pine (*Pinus contorta* var. *latifolia* Dougl.) ecosystem. Extensive forest areas have been decimated by this insect (Amman and others 1977; Safranyik and others 1974). Historically, millions of trees are killed yearly, and, during epidemics, more than a million trees can be killed in a single year on one National Forest. The beetle has killed an estimated 2 billion board feet per year since 1975 (Safranyik 1978). The beetle, like fire, has been active and has coexisted in lodgepole pine ecosystems almost as long as there has been lodgepole pine (Roe and Amman 1970). The large increase in ground fuel and associated increase in the probability of large, high-intensity fires following beetle epidemics suggests that the interaction between beetle infestations, fires, and lodgepole pine tends to perpetuate lodgepole pine, and hence, mountain pine beetle epidemics. Scattered individual trees may be victims, but more often entire groups of trees are killed (fig. 1). Unchecked, these groups expand with succeeding beetle generations, and eventually entire stands suffer heavy mortality over large contiguous areas (fig. 2).

Depending on landowner objectives, these losses can have a catastrophic impact. For example, the value of a mountain home may be severely reduced by mortality of high-value shade and ornamental trees. From the timber producer's standpoint, infestations seriously affect even flow and sustained yield and make the task of converting unmanaged to managed forest very difficult. Epidemics disrupt management plans and affect local, regional, and national economies. Downfall following infestations hampers access and use by big game, livestock, and humans. Infestations affect recreation and esthetics, increase fire hazards, affect water and watershed management, and may increase the proportion of trees infected by dwarf mistletoe (*Arceuthobium americanum* Nutt. ex. Engelm.) (Wellner 1978). On the other hand, some managers favor grassland over timberland, and a beetle epidemic causes them much less concern. They may, however, establish this preference without fully considering other resource values—among them soil, water, and vegetation stability.

Mountain pine beetle epidemics also have major impacts on roadless and wilderness areas and national parks. Because the beetle is such a profound change agent in lodgepole pine ecosystems, the resource values and management objectives of these lands are usually modified to some degree by an epidemic. For example, although the effect on water quality and quantity of these lands may be minimal (Wellner 1978), wildlife and visual resources can be impaired.

Most epidemics develop because there are large areas of unmanaged lodgepole pine forests. Periodically in these forests, endemic mountain pine beetle populations develop to epidemic levels. In an outbreak, the beetle thins from above, first killing the older, large-diameter, more open-grown trees. As populations build, beetles eventually kill smaller and younger lodgepole pine less desirable for brood production. In general, the beetle attacks and kills proportionately more large-diameter than small-diameter trees (Cole and Amman 1969) and kills trees of largest diameter each year of the infestation. Infestations die out when all or most of the large-diameter trees are killed (Amman 1977). The effect on productivity in stands containing an appreciable proportion of lodgepole pine (for example, >40 percent) is a residual stand composed of inferior trees that are unable to adequately exploit the extra growing space provided them. Productivity is also affected by additional mortality caused by sun-scald, snow, windthrow, or other causes (Wellner 1978).

Mortality and losses in timber yields can be reduced to acceptable levels if forest managers integrate pest

Figure 1.—Red-topped group of lodgepole pine trees killed by mountain pine beetle.

Figure 2.—High densities of red-topped lodgepole pine over large areas signify epidemic infestations.

management techniques developed for the mountain pine beetle into the timber management planning process and use appropriate methods wisely.

This management guide summarizes earlier published and unpublished technical information and recent findings of research and pest management specialists concerning the beetle and its host. It is intended to complement and supplement information contained in earlier guides (Safranyik and others 1974; Amman and others 1977; Berryman 1978; Cole and Amman 1980; Amman and Cole 1983). The objective of this guide is to synthesize information on the beetle and its host, methods for evaluating stand susceptibility, effects on various resources, coordination of silvicultural systems and practices, and integration of management for various resources with preventative management of mountain pine beetle populations.

These guidelines are a contribution to the Canada/U.S. Mountain Pine Beetle Action Plan and should be useful to forest planners, silviculturists, pest management specialists, and foresters charged with preventing or reducing losses to the mountain pine beetle in lodgepole pine forests.

THE BEETLE

Gene D. Amman
Intermountain Forest and Range
Experiment Station
Ogden, UT

Mark D. McGregor
Cooperative Forestry and Pest Management
Northern Region
Missoula, MT

BEHAVIOR, BIOLOGY, AND LIFE CYCLE

The first evidence of infestation usually consists of pitch tubes, where beetles entered the tree, and boring dust in bark cracks and at the base of trees (fig. 3). Infested trees remain green until spring, when they can be detected from a distance as foliage dries and changes to pale green, then to light orange, and finally to bright orange-red by July (fig. 4). Emergence holes made from mid-July through early August signify the brood has emerged from the tree to attack green trees (fig. 5).

The mountain pine beetle usually completes a single generation per year (fig. 6); however, up to 2 years may be required to complete the life cycle if cool temperatures at high elevations and in more northern latitudes delay development and emergence of beetles (Amman 1973; McCambridge 1974; Safranyik and others 1975).

Emergence and flight of new adults begin early in July and may continue through September. Although emergence may continue for a month or more, usually 80 percent of the beetles emerge within about 1 week (Rasmussen 1974). Initial attacks on pines usually occur on the lower 15 ft (4.4 m) of the bole. Unmated females make the initial attacks and release odors, called aggregating pheromones, that attract males and other females until a mass attack occurs on that tree and surrounding trees.

Figure 3.—Whitish to brownish pitch tubes on boles and similar-colored boring dust at base of tree indicate successful attack.

Figure 4.—Progressive fading of killed lodgepole pine trees in early summer. Greenish-yellow to tan-colored trees on left will look like tree at right within several weeks.

Figure 5.—Exit holes in lodgepole pine bark signify broods have emerged from the tree to attack others.

Figure 6.—General life cycle of mountain pine beetle in lodgepole pine. Color cycle of trees refers to the color change of foliage of successfully attacked trees, which is associated with the season and stage of the beetle's annual life cycle.

When populations are too light to mass-attack trees, or the tree is successful in repelling attacking beetles, the tree remains alive and is termed an unsuccessful attack or pitchout (fig. 7). Sometimes a portion of a tree is successfully infested and brood is produced without killing the tree. This is called a strip attack. Successful attacks are usually accomplished by a single generation of beetles. As populations increase from year to year, the mass-attack phenomena is heightened and larger groups of trees are infested and killed. The unmated female initiates the egg gallery and, following mating, lays eggs in alternating groups along the sides of the gallery. Egg galleries average about 12 inches long (31 cm) and are usually completed by late October when temperatures are too cold for the beetles to continue boring and ovipositing. Most eggs hatch in about 2 weeks; however, more time is required as temperatures begin to cool in the fall.

Newly hatched larvae feed on the phloem, constructing galleries that extend approximately at right angles to egg galleries (fig. 8). Larvae cease feeding in the fall, overwinter, and begin feeding again in April, completing development in June. Larvae change to pupae within cells excavated in the bark and sapwood. Pupae then transform to adults, usually from late June to mid-July.

In addition to the action of larvae feeding in the phloem, fungi and possibly other microorganisms aid in killing the infested trees (Safranyik and others 1975).

Figure 7.—Unsuccessful attack, called a pitchout. The tree was able to overcome the attacking beetles with a copious resin (pitch) response. Notice the absence of boring dust at base of tree.

New adults pick up blue stain fungi and probably other microorganisms in special structures located in their mouths while feeding in the bark before emerging. Blue stain fungal spores and yeast and bacterial spores are carried to newly attacked trees, where they develop, eventually spreading throughout the sapwood (fig. 9). The microorganisms commence growth in living phloem and xylem tissues soon after the beetle starts gallery construction. This hinders translocation in the xylem and makes moisture conditions under the bark more favorable for beetle development.

Figure 8.—Stripping the bark from trees in the progressive fading stage reveals egg and larval galleries, with the white larvae in various sizes of development. Brown granular material in galleries is feeding frass of the larvae.

Figure 9.—Blue-stain fungi introduced into the cambial layer by the attacking beetles ramify throughout the sapwood. The bluish-colored band affected by the fungi indicates the extent of sapwood.

BEETLE SURVIVAL

The most important factors affecting survival of the beetle brood and the expansion of beetle populations to epidemic levels are climate, habitat type, size and age of trees, phloem thickness, moisture content of phloem, stand structure, and stand density.

Climatic Factors

Climate can significantly influence the dynamics of beetle populations at extreme northern latitudes and at high elevations in more southerly latitudes (Amman 1976). At the lower elevational zone (below 4,920 ft [1 500 m] at lat. 49° N. to 8,528 ft [3 000 m] at lat. 39° N.), temperatures generally favor survival and multiplication (Amman and others 1977; Safranyik 1978), and the beetle poses a continuous threat to lodgepole pine of susceptible age and size. Above this zone, climate becomes progressively adverse to brood development and survival. Broods tend to undergo a 2-year cycle and become poorly synchronized with climate (Amman 1973) because the least cold-hardy life stages (egg, pupa) coincide with winter. Because of reduced brood survival, infestations become less frequent and intense with increasing elevation, although ample food supply exists (Amman and Baker 1972; Amman and others 1973). Therefore, stands of lodgepole pine at high elevations often contain a higher proportion of large-diameter trees than stands at low elevations.

Habitat Types

Habitat types are reflections of differences in environments. The beetle/lodgepole pine interaction varies in different habitat types. For example, in southeastern Idaho and northwestern Wyoming, 44 percent of the lodgepole pine stands were infested in the *Abies lasiocarpa/Vaccinium scoparium* habitat type (h.t.) between 6,500 and 8,500 ft (1 980 and 2 600 m) elevation; 92 percent were infested in the *Abies lasiocarpa/Paschistima myrsinities* h.t. between 6,500 and 7,800 ft (1 980 and 2 377 m) elevation; and 64 percent were actively infested in the *Pseudotsuga menziesii/Calamagrostis rubescens* h.t. between 6,000 and 7,800 ft (1 828 and 2 377 m) elevation (Roe and Amman 1970).

When habitat types were grouped into four classes on the Gallatin National Forest, MT, tree mortality from the beetles was shown to vary among habitat types and decreased in the following order: Douglas-fir, Engelmann spruce, subalpine fir, and lodgepole pine climax (figs. 10 and 11).

Among the dry habitat types, mortality of the lodgepole pine basal area in trees ≥8 inches (20 cm) d.b.h. ranged from 42 percent at 6,000 ft (1 828 m) elevation on *Pseudotsuga menziesii/Calamagrostis-Caru-Caru* phase h.t. to 25 percent at 8,000 ft (2 430 m) elevation on the *Abies lasiocarpa/Vaccinium scoparium-Vasc* phase h.t. Among moist habitat types mortality ranged from 40

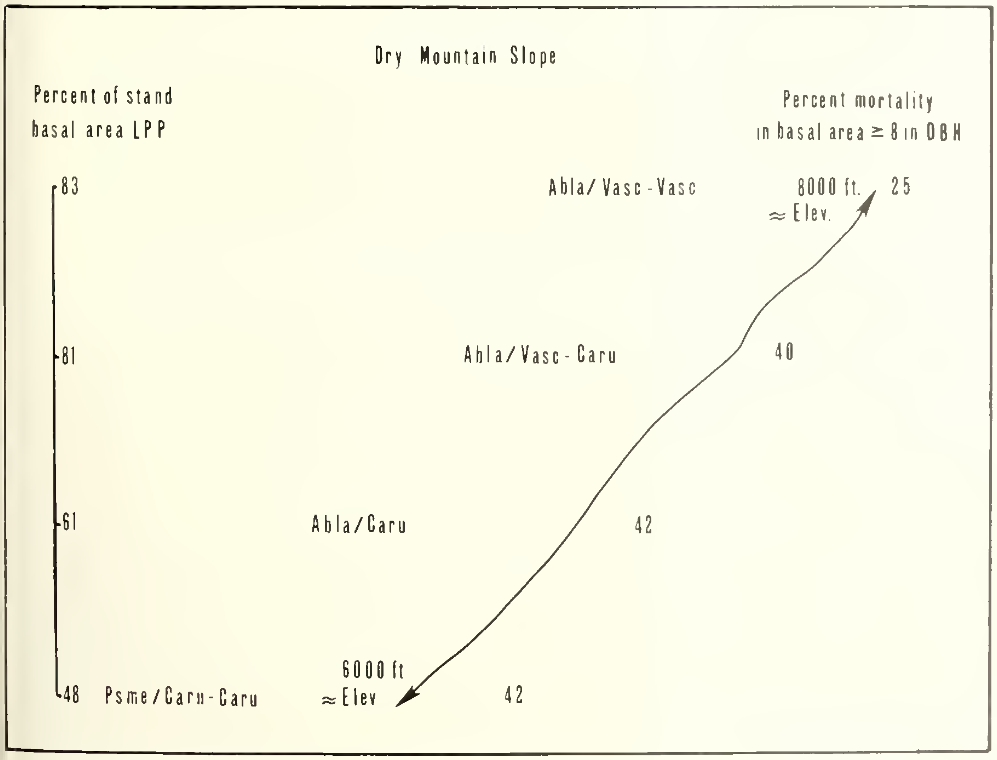


Figure 10.—Percentage of lodgepole pine basal area for trees 8 inches (20 cm) d.b.h. and larger killed by mountain pine beetle in relation to elevation, habitat type, and percentage lodgepole pine basal area in stands on dry aspects (McGregor 1978).

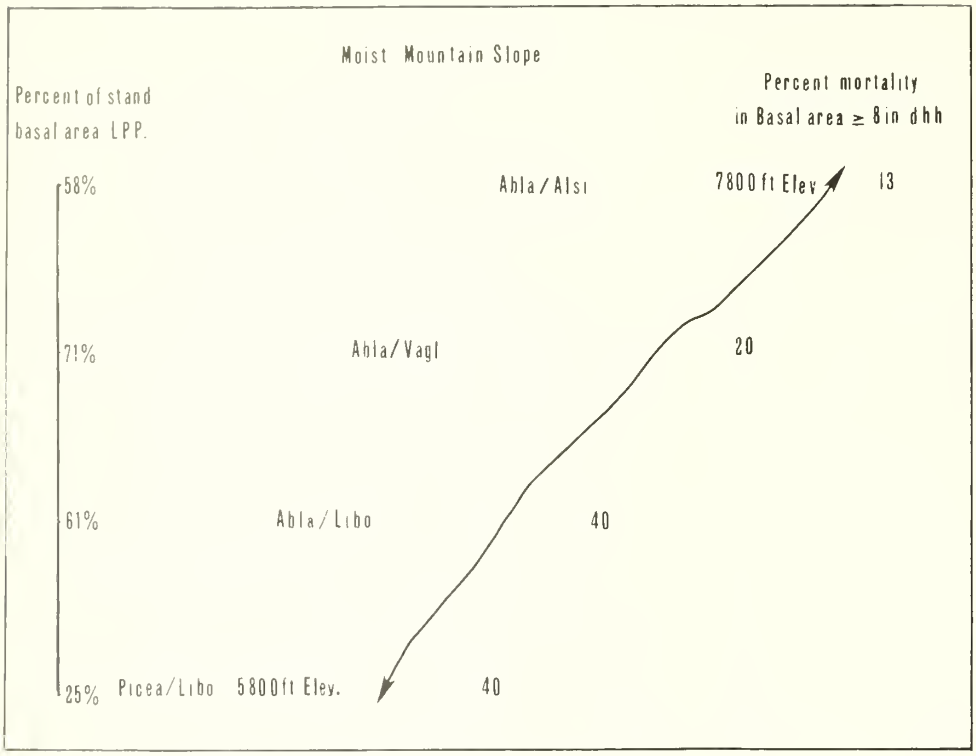


Figure 11.—Percentage of lodgepole pine basal area for trees 8 inches (20 cm) d.b.h. and larger killed by mountain pine beetle in relation to elevation, habitat type, and percentage lodgepole pine basal area in stands on wet aspects (McGregor 1978).

percent at 5,800 ft (1 727 m) elevation on the *Picea/Linnaea borealis* h.t. to 13 percent at 7,800 ft (2 377 m) elevation on *Abies lasiocarpa/Alnus sinuata* h.t. (McGregor 1978). Good sites generally have trees with thicker phloem than poorer sites. Since phloem thickness is the most important factor determining brood production where climate is not limiting, good sites can be expected to suffer more frequent and intense beetle infestations if unmanaged.

Tree Size and Age

Because the beetle selects and kills proportionately more large-diameter than small-diameter trees, large infestations require at least some lodgepole pine larger than 8 inches (20 cm) in diameter. The beetle selects the largest trees in a stand first, as well as over the life of the outbreak. Large trees usually have thicker phloem, the food of developing larvae, and maintain higher moisture levels throughout beetle development than small trees. These are the principal factors responsible for greater beetle production in large than small trees (Amman 1969, 1972; Cole and others 1976). The beetle's behavior in selecting trees of larger diameter is probably adaptive and related to the higher probability of encountering the thick phloem that results in higher progeny survival (Amman 1975).

When older stands of trees are infested, young trees in nearby stands are often attacked and killed. Because brood production and survival are low in young trees, however, young trees alone are not capable of sustaining an outbreak. The average age of trees in which outbreaks occur is about 80 years (Safranyik and others 1974; Amman and others 1977). Outbreaks in stands younger than 60 years have not been reported, a phenomenon that corresponds to general resistance of younger trees to blue stain fungi artificially inoculated under the bark. Resistance drops rapidly after age 60 and continues to decline with increased tree age (Shrimpton 1973). Outbreaks rarely begin in stands 60 to 80 years old. Phloem in trees under 80 years old is usually more spongy and resinous than that of older trees (Amman 1978). This may be because of larger cells and less phloem compression in phloem of young trees (Cabrera 1978).

Stand Structure and Density

Stand structure is important in beetle dynamics because of the beetle's preference for large-diameter lodgepole pines (Cole and Amman 1969). Losses of lodgepole increase as the proportion of lodgepole 9 inches (23 cm) or larger d.b.h. increases in stands (Amman and others 1973). As large-diameter trees are depleted from the stand, beetles turn to small trees; however, few beetles survive in small trees because of thin phloem and excessive drying. The number of beetles and infested trees subsequently declines (Cole and others 1976).

Under epidemic conditions, beetles depend upon the best trees in stands for a population buildup. Epidemics

usually start in full-crowned trees, but not necessarily the oldest or biggest, located along the outer edge of the timber bordering open rangeland or on lake and stream shores (Washburn and Knopf 1959). Trees at edges or in more open stands are usually growing faster than those within stands and, consequently, have thicker phloem. In more open stands, the proportional losses of lodgepole pine are therefore much greater (Amman 1978).

Stands with the greatest amount of dwarf mistletoe infection have proportionately fewer trees killed than do stands with little or no infection (McGregor 1978). This is because trees with medium-to-heavy dwarf mistletoe infection in the crown have significantly thinner phloem than do uninfected trees (Roe and Amman 1970).

The killing of the largest trees as they become mature, or slightly before they reach maturity in persistent and climax stands, suggests an adaptation by the beetle that results in a more continuous food supply for future generations (Amman 1977).

THE HOST

Robert D. Pfister
University of Montana
Missoula, MT

Dennis M. Cole
Intermountain Forest and Range
Experiment Station
Forestry Sciences Laboratory
Bozeman, MT

Lodgepole pine is one of the most widespread and important tree species in the coniferous forests of the western United States. It ranks fourth among timber types, covering about 13.3 million acres (5.38 million hectares), or 11 percent of the total area of commercial forest lands in this region (U.S. Department of Agriculture, Forest Service 1972). The three forms of lodgepole pine are found in distinct geographic regions:

- *P. contorta* var. *contorta*—Pacific Coast form (also known as shore pine)
- *P. contorta* var. *murryana*—Sierra-Cascade form
- *P. contorta* var. *latifolia*—Rocky Mountain and Intermountain forms

P. contorta var. *latifolia* is the preponderant form of commercial value and the one occurring where mountain pine beetle is an important part of the ecosystem. It is the form referred to throughout the rest of this paper.

Lodgepole pine forests in the Rocky Mountain and Intermountain areas provide many resources: cover for watersheds, forage for livestock, habitat for wildlife, wood products, and scenic and other recreational values. Because of the large proportion of area covered by lodgepole pine forests near and east of the Continental Divide, they are often the major provider of many of the above forest resources in this vast area.

Lodgepole pine has several notable silvical characteristics that strongly influence its management (Tackle 1955; Smithers 1957; D. M. Cole 1975). It is a seral, shade-intolerant species able to grow on most forest sites. It dominates large areas, mostly because of stand-replacing wildfires. In areas where closed cones prevail, stand-replacing fires have often resulted in overstocked lodgepole pine regeneration; however, successful fire control in the past several decades has resulted in fewer acres burned and a decreasing proportion of young, heavily overstocked stands.

Although lodgepole pine is a fast early grower, an overstocked stand soon suffers growth stagnation. Without stocking reduction, seriously stagnated stands can persist beyond normal rotation without ever producing merchantable material other than posts and poles. Growth rates of individual trees in stagnated stands can be improved by thinning, but for a given level of response, the time required for response is negatively correlated with degree of live crown ratio of leave trees and positively correlated with stocking and age (D. M. Cole 1975). Thus, the greater the degree of overstocking, the earlier the stand must receive stocking control if growth stagnation is to be minimized.

The major descriptors of stands—species composition, condition, and the age distribution of trees—greatly influence the practices chosen to prevent or reduce mortality from the beetle and their compatibility with other silviculture and management objectives. Composition (pure versus mixed species) and condition (healthy versus unhealthy) of stands are reasonably obvious, but age distribution is less so. Stands are often assumed to be even-aged when they are not. Such errors in identifying the age distribution can lead to an improper prescription from both silvicultural and entomological standpoints (D. M. Cole 1978). Tackle (1955) developed a preliminary classification for describing both pure and mixed lodgepole pine stands by age distribution and the developmental stage of the overstory versus the understory. A revised form of this classification is presented in figure 12. The revision redefines developmental stages to make them more consistent with contemporary economic rotations and ecological relationships with the mountain pine beetle. Specifically, the immature stage was redefined from 40 to 120 years to 40 to 80 years, and the mature stage from 120 to 140 years to 80 to 120 years. Although not all age classes are discussed as they might relate to mountain pine beetle infestation, most of the stand situations discussed in the following sections are identifiable in Tackle's classification.

Ecologically, the widespread occurrence of lodgepole pine is due to its capacity to grow in many different environments and the past prevalence of unchecked wildfires. The capacity to grow in a wide range of environments with a large number of other tree species illustrates its broad ecologic amplitude (Pfister and Daubenmire 1975). A comparison of this capacity in lodgepole pine and in other common associates is shown in figure 13, where the length of the occurrence bars indicates amplitude along a generalized environmental gradient.

The occurrence of lodgepole pine with and without association of other species is best explained in terms of the several successional roles that lodgepole pine can assume. These are described in the following section

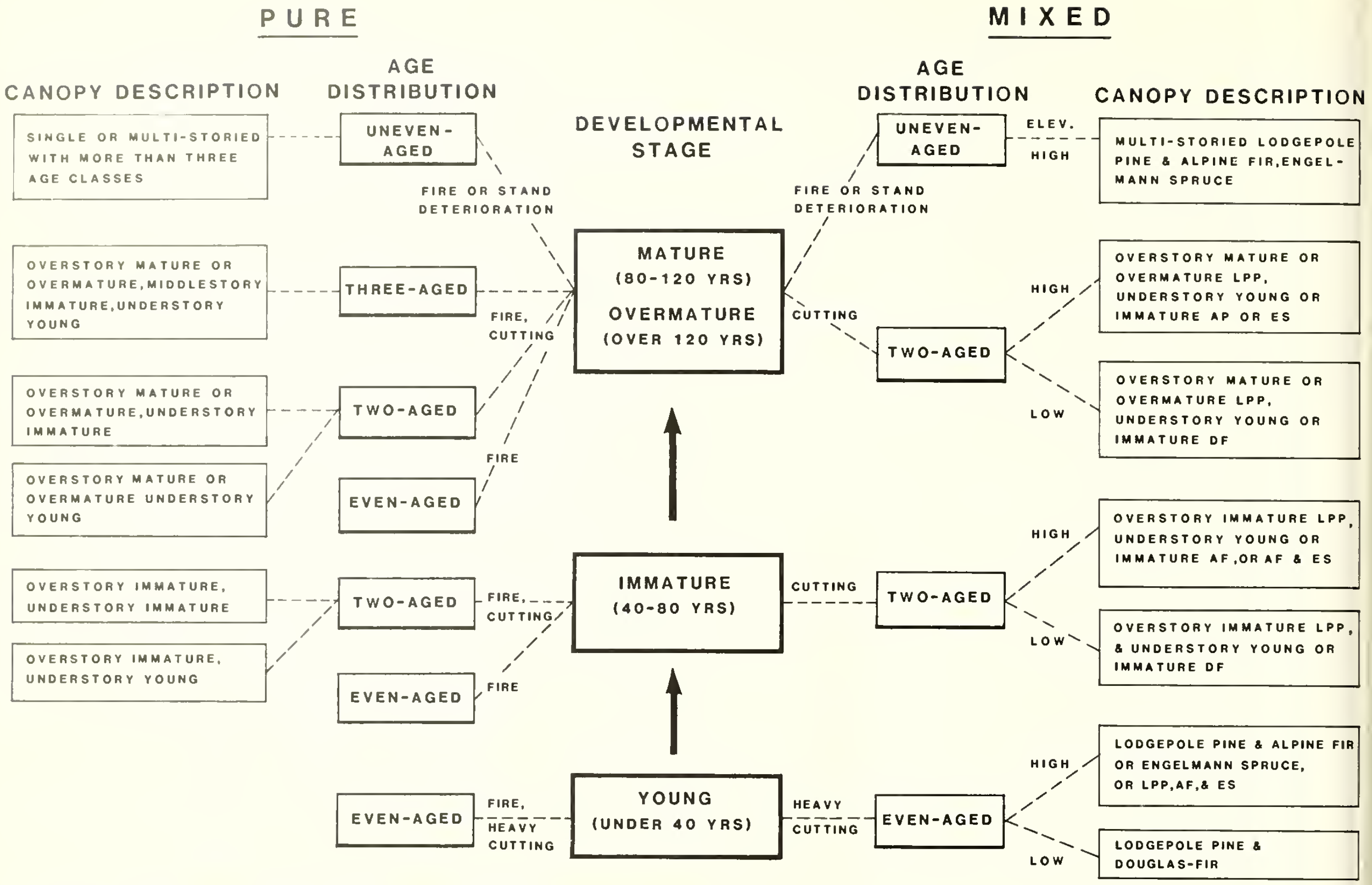


Figure 12.—Lodgepole pine stand classification (after Tackle 1955).

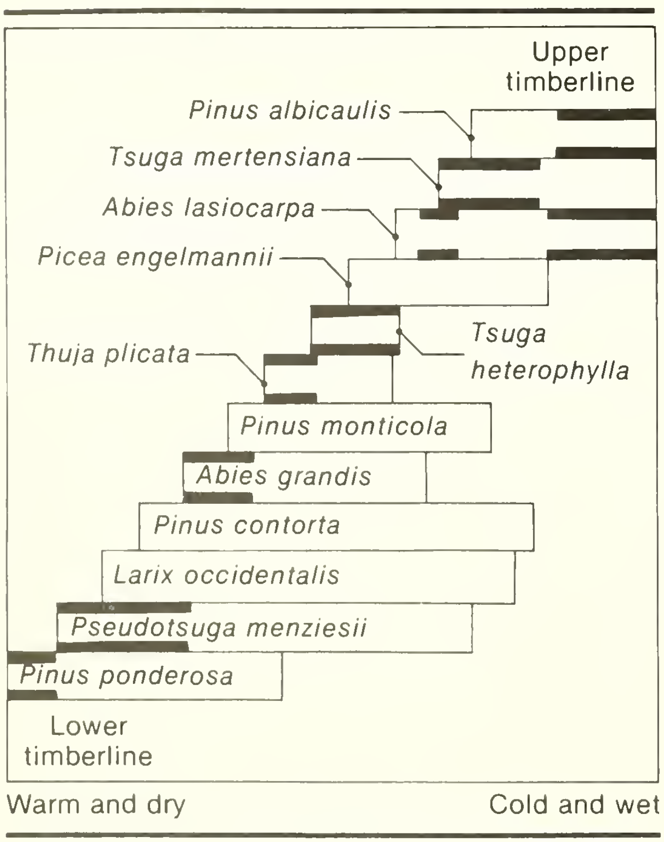


Figure 13.—Coniferous trees in the area centered on eastern Washington and northern Idaho; arranged vertically to show the usual order in which the species are encountered with increasing altitude. The horizontal bars designate relative upper and lower limits of the species' altitudinal range in which it can maintain a self-reproducing population. The heavy lines indicate range in which self-reproducing population can be maintained even in the face of intense competition (from Daubenmire 1966).

suffice it to say here that each of the successional roles manifests itself differently in one or more aspects of stand description, that is, composition, structure, condition, and form (age distribution). Understanding how these stand elements vary with successional role is important in interpreting mountain pine beetle/stand relationships and in determining likely consequences of silvicultural response to the mountain pine beetle—both discussed in later sections of this paper.

SUCCESSIONAL ROLES OF LODGEPOLE PINE

There are four basic successional roles for lodgepole pine (Pfister and Daubenmire 1975):

1. **Minor seral.**—Lodgepole pine is a minor component of young, even-aged, mixed species stands (fig. 14). It is replaced by shade-tolerant associates in 50 to 200 years; the more mesic the site, the sooner replacement occurs.

2. **Dominant seral.**—Lodgepole pine is often the dominant cover type of even-aged stands of habitat types where it exhibits a dominant seral role. In these cases, it often occurs with a vigorous understory of shade-tolerant species that will replace the lodgepole in 100 to 200 years (fig. 15). Succession occurs most rapidly where lodgepole pine and shade-tolerant associates become established simultaneously. Lodgepole pine gains dominance through rapid early growth, but shade-tolerant species persist and assume dominance as lodgepole pines die.

Figure 14.—Lodgepole pine in a minor seral successional role being replaced by Douglas-fir and Engelmann spruce. The pale green saplings are predominantly Douglas-fir.

Figure 15.—Pale and dying lodgepole pine contrast with healthy dark green crowns of subalpine fir and spruce in the background remnant of this stand clearcut and regenerated with lodgepole pine. This succession and regeneration pattern is typical where lodgepole pine occupies a major seral role and fire has interrupted succession of shade-tolerant species.

3. **Persistent.**—Lodgepole pine forms the dominant cover type of even-aged stands with little evidence of replacement by shade-tolerant species (fig. 16), which occur only as scattered individuals and apparently are too few and lack sufficient vigor to replace lodgepole pine. Lodgepole pine maintains dominance either because of inadequate seed sources for potential competitors or because the sites are poorly suited for other species. Although the cause-effect relationships are not known at this time, ecologists suggest that these sites be managed as if lodgepole pine were the climax species (Pfister and others 1977).

4. **Climax.**—Lodgepole pine is the only species capable of growing on particular sites and is self-perpetuating. In central Oregon, lodgepole pine forms an edaphic climax in frost pockets (Franklin and Dyrness 1973). In Wyoming, it forms an edaphic climax on granitic soils in portions of the Bighorn Mountains (Despain 1973) and on shallow, infertile soils of schist origin in portions of the Wind River Mountains. It also forms an edaphic climax on obsidian sands in the West Yellowstone Basin of the Gallatin National Forest and in Yellowstone National Park (fig. 17).

Figure 16.—Where lodgepole pine exhibits a persistent successional role, it dominates the site and affords little opportunity for establishment of other species.

Figure 17.—Climax lodgepole pine stand on obsidian sand at West Yellowstone, MT. Such pure stands are often uneven-aged and typically multistoried as shown here.

DESCRIPTIVE SUMMARY OF SUCCESSIONAL ROLES AND HABITAT TYPES OF LODGEPOLE PINE IN MONTANA AND NORTHERN IDAHO

Using the commonly accepted habitat-type classifications for Montana and northern Idaho (Daubenmire and Daubenmire 1968; Pfister and others 1977), we have summarized the habitat types where lodgepole pine occurs—according to geographic/climatic expression and successional role (tables 1 to 4). Following each table, habitat types represented are pictured with descriptive captions (figs. 18 to 59). These successional and pictorial summaries should be helpful to readers not having formal training in habitat-type identification; by providing an ecological framework for discussion, the summaries should facilitate the managerial process of developing integrated resource approaches for dealing with the mountain pine beetle problem. They will also help readers relate to the section "Occurrence of Lodgepole Pine Stands According to Habitat Type and Successional Role," where methods and results are presented of summaries of lodgepole pine acreage by successional role, habitat type, and size class for two National Forests containing large acreages of lodgepole pine. When habitat typing is completed throughout the lodgepole pine range, tables 1 to 4 can be expanded to include the additional information.

Table 1.—Habitat types where lodgepole pine is usually minor seral

Montana	Northern Idaho – Northwestern Montana	
Warm – dry	Pacific cool – moist	Cold – moist
PSME/SYAL	ABGR/CLUN	ABLA/LUHI
PSME/PHMA	ABGR/LIBO	TSME/MEFE
ABLA/CLPS	TSHE/CLUN	TSME/LUHI
	THPL/CLUN	

PSME/SYAL	*Pseudotsuga menziesii/Symphoricarpos albus* Douglas – fir/snowberry
PSME/PHMA	*Pseudotsuga menziesii/Physocarpus malvaceus* Douglas – fir/ninebark
ABGR/CLUN	*Abies grandis/Clintonia uniflora* Grand fir/queencup beadlily
ABGR/LIBO	*Abies grandis/Linnaea borealis* Grand fir/twinflower
TSHE/CLUN	*Tsuga heterophylla/Clintonia uniflora* Western hemlock/queencup beadlily
THPL/CLUN	*Thuja plicata/Clintonia uniflora* Western redcedar/queencup beadlily
ABLA/CLPS	*Abies lasiocarpa/Clematis pseudoalpina* Subalpine fir/virgin's bower
ABLA/LUHI	*Abies lasiocarpa/Luzula hitchcockii* Subalpine fir/smooth wood – rush
TSME/MEFE	*Tsuga mertensiana/Menziesia ferruginea* Mountain hemlock/menziesia
TSME/LUHI	*Tsuga mertensiana/Luzula hitchcockii* Mountain hemlock/smooth wood – rush

Figure 18.—The Pseudotsuga menziesii/Symphoricarpos albus *(PSME/SYAL) h.t. is found throughout Montana on moderately warm slopes and benches between 2,700 and 5,500 ft (823 and 1 676 m) elevation in northwestern and west-central Montana and 5,300 and 7,000 ft (1 615 and 2 134 m) elevation in eastern Montana.*

Figure 19.—The Pseudotsuga menziesii/Physocarpus malvaceus *(PSME/PHMA) h.t. occurs predominantly on cool and moist north- or east-facing slopes; between 2,000 and 5,700 ft (610 and 1 737 m) elevation in west-central Montana, 4,800 and 5,800 ft (1 463 and 1 768 m) in central Montana, and 5,100 and 6,700 ft (1 554 and 2 042 m) in south-central Montana.*

Figure 20.—The Abies grandis/Clintonia uniflora *(ABGR/CLUN) h.t. is found in relatively moist sites from 2,400 to 5,000 ft (732 to 1 524 m) elevation in northwestern and west-central Montana. It occurs on valley bottoms, benches, and on all aspects.*

Figure 21.—The Abies grandis/Linnaea borealis *(ABGR/LIBO) h.t. is a minor habitat in Montana occurring between 3,700 and 5,500 ft (1 128 and 1 676 m) elevation on northerly to southeasterly aspects.*

Figure 22.—The Tsuga heterophylla/Clintonia uniflora *(TSHE/CLUN) h.t. is a restricted h.t. in the extreme northwestern portion of Montana, with minor extensions east to Glacier National Park. It occurs mostly on valley bottoms, on benches, or on cool exposures at elevations from 1,800 to 4,000 ft (549 to 1 219 m).*

Figure 23.—The Thuja plicata/Clintonia uniflora *(THPL/CLUN) h.t. is common in northwestern Montana extending east to Glacier National Park, Swan River Valley, and south to the Bitterroot Range. It is typically associated with bottomlands, benches, and northerly exposures from 2,000 to 5,000 ft (610 to 1 524 m) elevation.*

Figure 24.—The Abies lasiocarpa/Clematis pseudoalpina *(ABLA/CLPS) h.t. is a warm dry habitat of the* Abies *series. It occurs on south- and west-facing slopes having limestone or calcium-rich substrates east of the Continental Divide in Montana at elevations between 6,000 and 8,000 ft (1 829 and 2 438 m).*

Figure 25.—The Abies lasiocarpa/Luzula hitchcockii *(ABLA/LUHI) h.t. is the major upper subalpine forest habitat type from the Continental Divide westward in Montana. It forms a zone extending over 700 ft (213 m) in elevation between the ABLA/XETE or ABLA/MEFE h.t.'s below and the PIAL/ABLA or LALY/ABLA h.t.'s.*

Figure 26.—The Tsuga mertensiana/Menziesia ferruginea *(TSME/MEFE) h.t. is associated with a mountain climate having strong oceanic influence; restricted to the border region of northwestern Montana, between 5,400 and 6,400 ft (1 646 and 1 951 m) elevation.*

Figure 27.—The Tsuga mertensiana/Luzula hitchcockii *(TSME/LUHI) h.t. is found along and adjacent to the Montana/Idaho divide between 6,000 and 6,500 ft (1 829 and 1 981 m) elevation.*

Table 2.—Habitat types where lodgepole pine is often dominant seral

Montana			Northern Idaho – Northwestern Montana
Warm – dry	**Cool – moist**	**Cold – dry**	**Warm-moist**
PSME/LIBO PSME/CARU	PICEA/PHMA	ABLA/CAGE ABLA/PIAL/VASC	ABLA/CLUN

PSME/LIBO	*Pseudotsuga menziesii/Linnaea borealis* Douglas – fir/twinflower
PSME/CARU	*Pseudotsuga menziesii/Calamagrostis rubescens* Douglas – fir/pinegrass
PICEA/PHMA	*Picea/Physocarpus malvaceus* Spruce/ninebark
ABLA/CAGE	*Abies lasiocarpa/Carex geyeri* Subalpine fir/elk sedge
ABLA/CLUN	*Abies lasiocarpa/Clintonia uniflora* Subalpine fir/queencup beadlily
ABLA – PIAL/VASC	*Abies lasiocarpa – Pinus albicaulis/Vaccinium scoparium* Subalpine fir – whitebark pine/grouse whortleberry

Figure 28.—The Pseudotsuga menziesii/Linnaea borealis *(PSME/LIBO) h.t. is a major habitat type in northwestern, west-central, and central Montana. It occurs on all but the wettest or driest sites, on moderate slopes, at elevations ranging from 2,600 to 4,000 ft (792 to 1 219 m) in northwestern Montana; 4,000 to 6,000 ft (1 219 to 1 829 m) in west-central Montana; and 5,000 to 6,500 ft (1 524 to 1 981 m) in central Montana.*

Figure 29.—The Psuedotsuga menziesii/Calamagrostis rubescens *(PSME/CARU) h.t. occurs at elevations from 2,700 ft (823 m) in northwestern Montana to 7,800 ft (2 377 m) in southwestern and south-central Montana. At lower elevations, it occurs on benches and north-facing upper slopes and mountainsides. At higher elevations, it is found in similar positions on south-facing slopes.*

Figure 30.—The Picea/Physocarpus malvaceous *(PICEA/PHMA) h.t. covers sizable areas on moist, north-facing slopes in south-central Montana on the Gallatin National Forest between 5,900 and 7,000 ft (1 798 and 2 134 m) elevation.*

Figure 31.—The Abies lasiocarpa/Carex geyeri *(ABLA/CAGE) h.t. encompasses some of the driest sites in Montana. On southerly aspects between 6,600 and 7,700 ft (2 012 and 2 347 m) elevation on the Gallatin National Forest and from 6,700 to 7,100 ft (2 042 to 2 164 m) elevation in Little Belt and Big Belt Mountains of central Montana.*

Figure 32.—The Abies lasiocarpa/Clintonia uniflora *(ABLA/CLUN) h.t. occurs on moist and warm sites in northwestern Montana in the Flathead River drainage at 3,200 to 5,500 ft (975 to 1 676 m) elevation.*

Figure 33.—The Abies lasiocarpa-Pinus albicaulis/Vaccinium scoparium *(ABLA-PIAL/VASC) h.t. is an extensive high-elevation habitat type east of the Continental Divide in all but driest mountain ranges. It is found on all exposures from 7,200 to 8,100 ft (2 195 to 2 469 m) elevation in central Montana, 8,000 to 8,800 ft (2 438 to 2 682 m) elevation in southwestern Montana, and 8,100 to 9,000 ft (2 469 to 2 743 m) elevation in south-central Montana.*

Table 3.—Habitat types where lodgepole pine is usually dominant seral

Montana			Northern Idaho – Northwestern Montana	
Dry	**Moist**	**Cold – moist**	**Cold – dry**	**Cold – moist**
PSME/JUCO	PSME/VACA	ABLA/CACA	ABGR/XETE	ABLA/MEFE
ABLA/CARU	PICEA/CLUN	ABLA/LIBO	PSME/VAGL	TSME/XETE
	PICEA/GATR	ABLA/VASC	ABLA/XETE	
	PICEA/LIBO			
	PICEA/SMST			
	PICEA/VACA			
	ABLA/VAGL			
	ABLA/ALSI			
	ABLA/ARCO			
	ABLA/GATR			

PSME/VAGL	*Pseudotsuga menziesii/Vaccinium globulare* Douglas-fir/blue huckleberry
PSME/JUCO	*Pseudotsuga menziesii/Juniperus communis* Douglas-fir/common juniper
PSME/VACA	*Pseudotsuga menziesii/Vaccinium caespitosum* Douglas-fir/dwarf huckleberry
PICEA/CLUN	*Picea/Clintonia uniflora* Spruce/queencup beadlily
PICEA/GATR	*Picea/Galium triflorum* Spruce/sweetscented bedstraw
PICEA/LIBO	*Picea/Linnaea borealis* Spruce/twinflower
PICEA/SMST	*Picea/Smilacina stellata* Spruce/starry Solomon's seal
PICEA/VACA	*Picea/Vaccinium caespitosum* Spruce/dwarf huckleberry
ABGA/XETE	*Abies grandis/Xerophyllum tenax* Grand fir/beargrass
ABLA/GATR	*Abies lasiocarpa/Galium triflorum* Subalpine fir/sweetscented bedstraw
ABLA/CACA	*Abies lasiocarpa/Calamagrostis canadensis* Subalpine fir/bluejoint
ABLA/LIBO	*Abies lasiocarpa/Linnaea borealis* Subalpine fir/twinflower
ABLA/MEFE	*Abies lasiocarpa/Menziesia ferruginea* Subalpine fir/menziesia
ABLA/XETE	*Abies lasiocarpa/Xerophyllum tenax* Subalpine fir/beargrass
TSME/MEFE	*Tsuga mertensiana/Menziesia ferruginea* Mountain hemlock/menziesia
ABLA/VAGL	*Abies lasiocarpa/Vaccinium globulare* Subalpine fir/blue huckleberry
ABLA/VASC	*Abies lasiocarpa/Vaccinium scoparium* Subalpine fir/grouse whortleberry
ABLA/ALSI	*Abies lasiocarpa/Alnus sinuata* Subalpine fir/Sitka alder
ABLA/CARU	*Abies lasiocarpa/Calamagrostis rubescens* Subalpine fir/pinegrass
ABLA/ARCO	*Abies lasiocarpa/Arnica cordifolia* Subalpine fir/heartleaf arnica

Figure 34.—The Pseudotsuga menziesii/Vaccinium globulare *(PSME/VAGL) h.t. occurs on cold, well drained slopes at elevations between 4,300 and 6,800 ft (1 311 and 2 073 m) on the Lolo and Bitterroot National Forests.*

Figure 35.—The Pseudotsuga menziesii/Juniperus communis *(PSME/JUCO) h.t. is a common habitat type in cool-dry environments of central and northwestern Montana, occurring on the Lewis and Clark, Deerlodge, and Beaverhead National Forests. It is one of the driest h.t.'s supporting lodgepole pine in the Douglas-fir series. Juniper is typically sparse because of stand density.*

Figure 36.—The Pseudotsuga menziesii/Vaccinium caespitosum *(PSME/VACA) h.t. is a widely occurring h.t. in Montana. It is found on warm and moist benches and gentle slopes from 2,500 to 3,800 ft (762 to 1 158 m) in northwestern Montana, 2,900 to 4,500 ft (884 to 1 372 m) in west-central Montana, and 5,200 to 6,400 ft (1 585 to 1 951 m) east of the Continental Divide.*

Figure 37.—The Picea/Clintonia uniflora *(PICEA/CLUN) h.t. occurs in moist environments on benches and gentle north slopes in northwestern Montana from 3,000 to 4,100 ft (914 to 1 250 m) elevation in the Flathead Valley and occasionally on the Kootenai National Forest.*

Figure 38.—The Picea/Galium triflorum *(PICEA/GATR) h.t. is found on cool, moist sites, bordering streams, or on moist toe-slopes in south-central Montana between 6,000 and 7,000 ft (1 829 and 2 134 m) elevation.*

Figure 39.—The Picea/Linnaea borealis *(PICEA/LIBO) h.t. is found on cool, well drained benches and gentle northeast slopes east of the Continental Divide in Montana between 4,200 and 7,200 ft (1 280 and 2 195 m) elevation.*

Figure 40.—The Picea/Smilacina stellata *(PICEA/SMST) h.t. occurs east of the Continental Divide from the Lewis and Clark National Forest to Yellowstone Park. It is found on warm, moist benches and lower slopes mostly between 5,000 and 7,000 ft (1 524 and 2 134 m) elevation.*

Figure 41.—The Picea/Vaccinium caespitosum *(PICEA/VACA) h.t. is common in northwestern Montana between 3,100 and 4,200 ft (945 and 1 280 m) elevation. It is restricted to benchlands at higher elevations eastward in Montana.*

Figure 42.—The Abies grandis/Xerophyllum tenax *(ABGR/XETE) h.t. is common on well-drained slopes between 4,700 and 5,300 ft (1 433 and 1 615 m) elevation in western portions of the Lolo and Bitterroot National Forests.*

Figure 43.—The Abies lasiocarpa/Galium triflorum *(ABLA/GATR) h.t. occurs throughout the Montana Rockies on moist bottomlands, benches, northern exposures, and occasionally seepage areas on southern exposures between 5,000 and 6,800 ft (1 524 and 2 073 m) elevation except on the Gallatin National Forest, where it occurs from 6,300 to 7,700 ft (1 920 to 2 345 m).*

Figure 44.—The Abies lasiocarpa/Calamagrostis canadensis *(ABLA/CACA) h.t. is the major type on wet sites at high elevations, except in northwestern Montana. It occurs at elevations from 6,000 to 7,500 ft (1 829 to 2 286 m) in west-central Montana and from 7,000 to 8,500 ft (2 134 to 2 591 m) east of the Continental Divide.*

Figure 45.—The Abies lasiocarpa/Linnaea borealis *(ABLA/LIBO) h.t. is associated with relatively moist sites on north-facing slopes and benches throughout the Montana Rockies. It occurs mostly at elevations of 5,000 to 7,000 ft (1 524 to 2 134 m).*

Figure 46.—The Abies lasiocarpa/Menziesia ferruginea *(ABLA/MEFE) h.t. is abundant in the moist, higher elevations of western Montana and extends slightly eastward of the Continental Divide near Hebgen Lake and the Madison Range in southwestern Montana.*

Figure 47.—The Abies lasiocarpa/Xerophyllum tenax *(ABLA/XETE) h.t. occurs west of the Continental Divide on steep, dry exposures between 5,200 and 7,000 ft (1 585 and 2 134 m) elevation.*

Figure 48.—The Tsuga mertensiana/Xerophyllum tenax *(TSME/XETE) h.t. is usually found at 5,500 to 6,500 ft (1 676 to 1 981 m) elevation on upper slopes and ridges only in the extreme northwestern part of Montana.*

Figure 49.—The Abies lasiocarpa/Vaccinium globulare *(ABLA/VAGL) h.t. occurs on moist north- or east-facing slopes on cool benches, between 6,000 and 7,800 ft (1 829 and 2 377 m) elevation. It is largely restricted to areas near or east of the Continental Divide.*

Figure 50.—The Abies lasiocarpa/Vaccinium scoparium *(ABLA/VASC) h.t. is one of the most abundant types near and east of the Continental Divide. It occurs mostly on gentle, well-drained slopes, broad ridges, and benches between 7,000 and 8,000 ft (2 134 and 2 438 m) elevation. It is also locally common at 5,000 to 5,700 ft (1 524 to 1 737 m) in dry mountains south and west of Eureka, MT.*

Figure 51.—The Abies lasiocarpa/Alnus sinuata *(ABLA/ALSI) h.t. occurs throughout the mountains of Montana as a scattered h.t. on cool and moist north-facing slopes between 6,500 and 7,500 ft (1 981 and 2 286 m) elevation, except in northwestern Montana, where it occurs between 5,000 and 5,800 ft (1 524 and 1 768 m).*

Figure 52.—The Abies lasiocarpa/Calamagrostis rubescens *(ABLA/CARU) h.t. occurs east of the Continental Divide on warm, dry slopes. It is found at elevations between 6,500 and 7,700 ft (1 981 and 2 347 m) in the Centennial Mountains of southwestern Montana and in the Gallatin National Forest and is common at elevations between 5,000 and 6,300 ft (1 524 and 1 920 m) in the Front Range west of Great Falls, MT.*

Figure 53.—The Abies lasiocarpa/Arnica cordifolia *(ABLA/ARCO) h.t. is a moist, relatively cool h.t. occurring on bench-like uplands and north-facing slopes of semiarid mountains east of the Continental Divide. It occurs on the Beaverhead National Forest at elevations from 7,600 to 8,400 ft (2 316 to 2 560 m) and in the Little Belt Mountains, where it usually occurs on limestone substrates at elevations from 6,900 to 7,600 ft (2 103 to 2 316 m).*

Figure 54.—The Abies lasiocarpa/Vaccinium caespitosum *(ABLA/VACA) h.t. is confined largely to well-drained sites on benchlands and in frosty basins where cold air accumulates at 6,000 to 7,200 ft (1 829 to 2 195 m) elevation near the Continental Divide and in the Little Belt Mountains. Lodgepole pine dominates the overstory, whereas regeneration is lodgepole pine, alpine fir, and Douglas-fir.*

Table 4.—Habitat types where lodgepole pine is persistent/climax

	Central and Eastern Montana
	Cold – dry community types
	ABLA/VACA PICO/VACA PICO/LIBO PICO/CARU PICO/VASC PICO/PUTR
ABLA/VACA	*Abies lasiocarpa/Vaccinum caespitosum* Subalpine fir/dwarf huckleberry
PICO/VACA	*Pinus contorta/Vaccinium caespitosum* Lodgepole pine/dwarf huckleberry
PICO/LIBO	*Pinus contorta/Linnaea borealis* Lodgepole pine/twinflower
PICO/CARU	*Pinus contorta/Calamagrostis rubescens* Lodgepole pine/pinegrass
PICO/VASC	*Pinus contorta/Vaccinium scoparium* Lodgepole pine/grouse whortleberry
PICO/PUTR	*Pinus contorta/Purshia tridentata* Lodgepole pine/bitterbrush

Figure 55.—The Pinus contorta/Vaccinium caespitosum *(PICO/VACA) h.t. occurs east of the Continental Divide on benches and gentle slopes between 6,200 and 7,200 ft (1 890 and 2 195 m) elevation. Some stands occur at 4,800 to 6,500 ft (1 463 to 1 981 m) west of the Divide.*

Figure 56.—The Pinus contorta/Linnaea borealis *(PICO/LIBO) h.t. is common east of the Continental Divide between elevations of 6,500 and 7,200 ft (1 981 and 2 195 m) on benchlands and north-facing midslopes.*

Figure 57.—The Pinus contorta/Calamagrostis rubescens *(PICO/CARU) h.t. is found near and east of the Continental Divide at 5,900 to 6,800 ft (1 798 to 2 073 m) elevation on cool exposures and benches and between 6,600 and 7,500 ft (2 012 and 2 286 m) on south-facing slopes.*

Figure 58.—The Pinus contorta/Vaccinium scoparium *(PICO/VASC) h.t. occurs at elevations of 6,000 to 7,000 ft (1 828 to 2 134 m) near and east of the Continental Divide. It is usually found in relatively cool, dry environments on gentle middle and upper slopes and broad ridgetops.*

Figure 59.—The Pinus contorta/Purshia tridentata *(PICO/PUTR) h.t. occurs on obsidian-sand benchland near West Yellowstone, MT, at 6,600 ft (2 012 m) elevation. This environment is subject to summer frosts.*

ASSESSING STAND HAZARD AND RISK

HAZARD RATING AND PREDICTING TREE LOSS IN UNMANAGED STANDS

Gene D. Amman
Intermountain Forest and Range Experiment Station
Ogden, UT

Mark D. McGregor
Cooperative Forestry and Pest Management
Northern Region
Missoula, MT

Effective systems for assessing susceptibility to the mountain pine beetle of managed and unmanaged stands are essential in designing and accomplishing sound multiple resource forest management where lodgepole pine is an important part of the forest cover.

Which of the lodgepole pine stands are most susceptible to beetle outbreak and how many trees will be lost depend upon risk (Safranyik 1982). Reliable methods are not available to predict when an outbreak will develop (Shrimpton and Thomson 1981), but the stand susceptibility and extent of losses can be predicted.

Stand Hazard Rating

As foresters implement strategies to prevent, minimize, or reduce losses to the mountain pine beetle, they will be faced with new challenges in managing the new forest to rotation. Not only will they be faced with implementing a variety of strategies to minimize damage from pests infesting immature lodgepole pine stands, they will also need to consider various hazard and risk rating procedures for assessing susceptibility of managed stands.

Several methods of rating lodgepole pine stands for susceptibility to outbreaks have been developed (Amman and others 1977; Berryman 1978; Mahoney 1978; Safranyik and others 1974; Schenk and others 1980; Waring and Pitman 1980). The methods are designed to help land managers identify high-hazard stands so that losses can be minimized and particular objectives can be met, whether they pertain to timber harvest, wildlife, hydrology, esthetics, or other aspects. Several of these methods utilize data normally obtained from standard inventory surveys, a highly desirable attribute (Lorio 1978; Hedden 1981).

All of the hazard rating systems for mountain pine beetle were developed in unmanaged stands, and none has been tested exclusively in managed stands. Except for Amman and others (1977) and Safranyik and others (1974), these hazard rating methods are based on measurement of tree vigor. Mitchell and others (1983) applied the Waring and Pitman (1980) method to small thinnings made several years before a mountain pine beetle outbreak. The results suggest that growth efficiency may be used as an indicator of susceptibility to mountain pine beetle infestation. Amman (in press), however, found no preference by mountain pine beetle for trees of low growth efficiency and, in many cases, trees killed by mountain pine beetle exceeded the threshold considered resistant to mountain pine beetle attack. None of the vigor-related hazard rating systems improved predictions over that of the Amman and others (1977) system (Amman, in press).

The Amman and others (1977) and Safranyik and others (1974) hazard rating systems are based on three major factors that affect mountain pine beetle survival—climate, tree age, and tree size.

Climatic suitability of stands for mountain pine beetle in the United States is based on observed lodgepole pine mortality for many different elevations and latitudes from Colorado to the Canadian border (fig. 60). Beetle populations do well at low elevations where temperatures are optimum for their development. Brood development slows as elevations increase until, at high elevations, 2 years may be required to complete a generation (Amman 1973). Delay in development frequently results in beetles entering winter in stages more prone to winter kill. In addition, beetles in a 2-year cycle are subjected to mortality factors for a much longer time than during a 1-year cycle. Adverse effects on the beetle populations associated with increasing elevation are reflected in reduced tree mortality.

Average stand age is more an indicator of phloem suitability than a measure of tree vigor, as far as the beetle is concerned. Lodgepole pine >80 years of age have considerably firmer phloem that contains fewer and smaller cortical resin ducts. Such trees dry more slowly than younger trees, thus providing adequate moisture throughout beetle development (McGregor and others 1981).

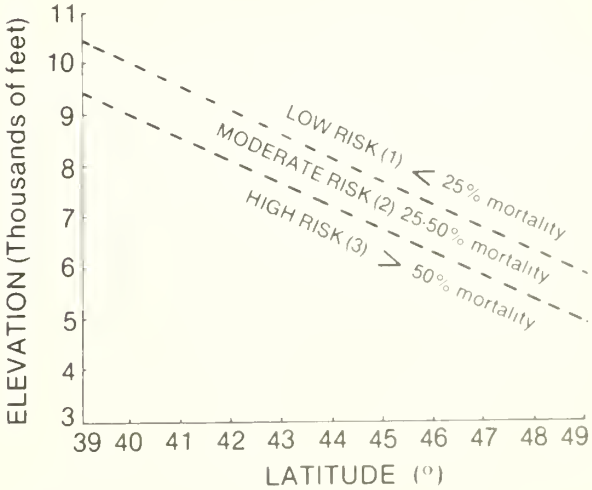


Figure 60.—Risk of mountain pine beetle infestation in unmanaged lodgepole pine can be defined by zones of elevation and latitude. Percentage of mortality is for trees 8.5 inches d.b.h. (21.6 cm) and larger (Amman and others 1977).

Average d.b.h. of lodgepole pine is used because of the beetle's strong preference for larger trees, which generally have thicker phloem and dry more slowly than small-diameter trees. Brood production is strongly influenced by phloem thickness and tree moisture (Cole and others 1976). Unmanaged lodgepole pine stands with an average d.b.h. ≥8 inches (20 cm) can be expected to have a sufficient number of larger diameter trees for the beetle population to build up and be sustained.

Average elevation, stand age, and d.b.h. are obtained during a standard stand examination. For stands <20 acres (8.0 ha), a systematic random or grid sample of 10 variable plots is recommended. For larger stands, 20 variable plots are suggested. A basal area factor giving 10 count trees per variable plot is usually sufficient. Age is obtained from increment cores taken at breast height from three trees nearest to plot center that are 5 inches (13 cm) d.b.h. or larger. Average stand diameter is determined from measurement of all lodgepole pine trees ≥5 inches (13 cm) d.b.h. within each plot. Risk values are assigned to each of three factors—climatic suitability, average tree age, and d.b.h. (fig. 60). Greater than 50 percent mortality can occur in high-risk stands, 25 to 50 percent in moderate-risk stands, and <25 percent in low-risk stands.

Only the Amman and others (1977) hazard rating system has been tested extensively in the United States. Its use on the Kootenai National Forest in western Montana gave very good results (McGregor and others 1981). Therefore, until the other hazard rating systems have been tested on a large scale, we recommend the Amman and others (1977) system.

Extensive tests of all the hazard rating systems are planned as part of the Canada/United States mountain pine beetle agreement (USDA Forest Service 1983). From these tests, the geographic area of applicability for each hazard rating system will be determined, and new combinations of factors that may be better predictors of mountain pine beetle outbreak and tree loss will be explored. Therefore, until the various susceptibility and damage concepts receive additional field evaluation and testing, we do not recommend applying them to managed situations.

After stands have been rated for beetle hazard, the next step is to determine the expected rate and amount of tree loss if a stand becomes infested. The probability of a tree becoming infested depends on the susceptibility of the tree, the length of the flight period, the size of the attacking beetle population, and environmental conditions of the stand (Cole and McGregor 1983). A rate of loss model incorporating these factors has recently been developed (Cole and McGregor 1983). It is based on the Reed and Frost model (Abbey 1952).

The rate of loss model assumes optimum conditions for the beetle throughout the life of the epidemic; however, detrimental conditions can impede beetle populations and cause actual tree losses to be less than predicted. Although actual and predicted tree losses are usually similar for the larger diameter classes where epidemics begin, the model tends to overestimate losses in the smaller diameter classes when conditions are less than optimum for the beetle. This bias is not considered detrimental, but rather helpful, since it allows examination of "worst case" scenarios. Such examinations are made possible by looking at other measures of loss in addition to number of trees killed.

The rate of loss model has been integrated with the INDIDS model (Bousfield 1981) to estimate mortality trends for already infested stands and to obtain loss estimates in cubic and board foot volume for green stands if they become infested. The INDIDS model is used to analyze forest insect and disease survey data collected from variable or fixed plots. It summarizes, by tree species, size class, and damage class, the loss to be expected in number of trees, basal area, and volume killed per acre.

The Amman and others model is useful for classifying unmanaged stands according to high, moderate, and low classes of susceptibility. The rate of loss model provides a method for predicting which of the high-hazard stands will sustain the greatest amount of loss over time.

CONCEPTS FOR EVALUATING SUSCEPTIBILITY OF MANAGED STANDS

Mark D. McGregor
Cooperative Forestry and Pest Management
Northern Region
Missoula, MT

Various methods previously discussed are available for hazard rating unmanaged lodgepole pine stands. As foresters implement strategies to prevent, minimize, or reduce losses to the mountain pine beetle, they will be faced with new challenges in managing the new forest to rotation. Not only will they be faced with implementing a variety of strategies to minimize damage from pests of immature lodgepole pine stands, they will also need to consider various hazard and risk rating procedures for assessing susceptibility of managed stands.

Sufficiently reliable data are available to verify present hazard and risk rating systems for unmanaged lodgepole pine stands; however, in managed forests, additional parameters may become evident and will thus be useful for developing susceptiblity ratings for managed stands. Some of the same parameters used to define susceptibility (hazard) may also be applicable for predicting the amount of loss (risk); however, finer resolution of susceptibility and damage concepts appears necessary for classifying managed stands into hazard and risk categories.

Descriptors that might improve prediction of susceptibility in managed stands are site, habitat type, growth rate, crown ratio, phloem quality and physiological maturity, stand density, slope, aspect, and disease. These factors do not diminish the importance of average d.b.h. and age of lodgepole pine, elevation, and climate.

Various hazard and risk concepts that reflect measures of vigor, stress, resistance, and susceptibility have been and are being tested throughout the Western United States and Canada. Although some of the methods for determining susceptibility have been extensively tested

and work well for wide geographic areas, others have been tested only on a limited basis and are still under scrutiny. Information obtained from evaluations over an extensive geographic area might provide additional data on why some systems work best in some geographic areas and not in others.

We know from basal area and diameter limit cuts that mortality from mountain pine beetle is prevented or significantly reduced for 5 to 10 years following cutting (Cole and Cahill 1976; Cole and others 1983; Cole and McGregor, in press; McGregor and others, in press). Initial results appear favorable, but further evaluations are needed to determine if low levels of loss will persist.

Why various cutting prescriptions (other than clearcut) reduce infestation levels is still under evaluation. Established demonstration areas and establishment of some additional areas should provide data that will further explain cause and effect relationships. Until the various susceptibility and damage concepts receive additional field evaluation and testing, we do not recommend applying them to managed situations. Time will permit testing them for their efficacy under epidemic beetle pressure. Until this is done, we caution against their use for managed stands.

EFFECTS OF OUTBREAKS IN RELATION TO HOST OCCURRENCE AND RESOURCE CONCERNS

OCCURRENCE OF LODGEPOLE PINE STANDS ACCORDING TO HABITAT TYPE AND SUCCESSIONAL ROLE

Dennis M. Cole
Intermountain Forest and Range
Experiment Station
Forestry Sciences Laboratory
Bozeman, MT

The previously described successional roles of lodgepole pine in the habitat types in which they are expressed provide a basic ecological criterion for summarizing and analyzing the quantitative and qualitative effects of the lodgepole pine/mountain pine beetle interaction on various resources (Pfister 1975). They also provide a basis for evaluating appropriate silvicultural management responses to the mountain pine beetle problem in regard to immature stand management, regeneration silviculture, wildlife values, fuels management, watershed values, and other resource considerations.

Forest inventories of the Gallatin and Flathead National Forests provide examples of how the habitat type-successional role criterion allows us to summarize and describe potential mountain pine beetle problems. The inventories were summarized according to habitat type acreage of lodgepole pine in basal area and size classes historically associated with significant mountain pine beetle damage levels (tables 5 and 6). The Gallatin and Flathead National Forests were chosen to allow contrast of the successional roles and habitat type acreage of lodgepole pine in a forest east of the Continental Divide (Gallatin), where lodgepole pine is a more predominant and persistent cover type, with a forest west of the Divide (Flathead), where mixed-species stands more commonly occur. From tables 5 and 6, data were further grouped to show overall occurrence of lodgepole pine by successional role (table 7) and to show percentage of forested land by successional role in stocking classes and size classes susceptible to the beetle (tables 8 and 9). Such summaries provide valuable information for assessing potential for future losses to the mountain pine beetle and for designing programs to prevent or limit them.

The type of information found in tables 5 and 6 can be used in conjunction with the unmanaged stand hazard rating system previously discussed and mountain pine beetle damage surveys to develop probabilities on time and severity of future attacks within individual habitat types. To be used in this way, damage surveys must have sampling designs and habitat classifications that are compatible with the sampling design and habitat classifications of the forest inventory.

Tables 5 and 6 can likewise be used to supplement the rudimentary guidelines developed by Forest planning teams for identifying preferred silvicultural systems for managing major damaging pests (table 10). This was done by computing the proportion of the Gallatin and Flathead National Forests in successional roles and susceptibility classes and summarizing the silvicultural alternatives applicable to each (table 11).

Tables 5 to 9 and 11 provide specific information for answering several of the questions posed by Rost (1978) concerning critical information needs of managers responsible for managing lodgepole pine forests in the face of the mountain pine beetle threat: (1) What is the abundance of the host species? (2) Is it widespread or isolated? (3) Is the total host population susceptible to attack? If not, what proportion is? (4) Are other species present or possible?

The tables provide a basis for assessing opportunities on the Gallatin and Flathead Forests for creating species and age-class diversity by varying species composition and size and rotation objectives of management—according to the location and area of the various habitat types where lodgepole pine occurs in different diameter and basal area classes.

To illustrate, we will use tables 5 to 9 and 11 to examine some similarities and differences in the extent of the mountain pine beetle problem and silvicultural alternatives for addressing them—in relation to the occurrence by successional role of lodgepole pine in the Gallatin and Flathead National Forests.

Table 5.—Successional role of lodgepole pine by habitat type (h.t.)—Gallatin National Forest

Successional role	H.t. abbreviation	H.t. area on NF		Stands where ≥20% of BA is in LPP exceeding following sizes: LPP >5" d.b.h. Acres	Mean BA[1]	Mean LPP BA[1]	LPP ≥7" d.b.h. Acres	Mean BA[1]	Mean LPP BA[1]	LPP ≥8" d.b.h. Acres	Mean BA[1]	Mean LPP BA[1]
		Acres	*Percent*		*Ft²*			*Ft²*			*Ft²*	
Minor seral												
	PSME/PHMA – CARU	15,176	18.5	0	0	0	0	0	0	0	0	0
	PSME/AGSP	6,453	.4	0	0	0	0	0	0	0	0	0
	PIFL/JUCO	28,188	1.6	0	0	0	0	0	0	0	0	0
	PSME/CAGE	19,683	1.1	0	0	0	0	0	0	0	0	0
	PSME/ARCO	9,150	.5	0	0	0	0	0	0	0	0	0
	PICEA/PHMA	29,683	1.7	0	0	0	0	0	0	0	0	0
	PICEA/GATR	4,112	.2	0	0	0	0	0	0	0	0	0
	PIAL/ABLA	114,689	6.6	0	0	0	0	0	0	0	0	0
	PIAL/FEID	5,471	.3	4,460	44	29	4,460	44	11	4,460	44	11
	PSME/FEID	54,204	3.1	8,871	49	25	8,871	49	21	8,871	49	21
	PSME/PHMA	82,491	4.8	5,542	139	40	5,542	139	40	0	0	0
	PSME/PHMA – PHMA	66,528	3.8	14,487	123	61	7,682	126	61	7,682	126	41
	PSME/SYAL	55,560	3.2	25,735	82	44	25,735	82	28	9,665	127	40
	PSME/SYAL – SYAL	30,573	1.8	2,320	40	13	2,320	40	13	2,320	40	13
	PSME/SYAL – CARU	17,736	1.0	7,253	114	41	7,253	114	34	7,253	114	34
	PSME/SPBE	4,253	.2	2,578	160	133	2,578	160	120	2,578	160	93
	ABLA/CLPS	61,326	3.5	2,399	149	80	2,399	149	80	2,399	149	80
	ABLA/CAGE – PSME	87,440	5.0	44,027	111	59	36,737	103	59	31,662	112	69
	ABLA – PIAL/VASC	219,776	18.5	139,550	149	65	139,550	149	61	133,402	146	58
Major seral												
	PSME/CARU-CARU	23,645	1.4	17,084	100	53	17,084	100	57	17,084	100	57
	ABLA/ALSI	6,355	.4	6,355	147	52	6,355	147	46	6,355	147	43
	ABLA/ARCO	57,151	3.3	16,180	146	69	16,180	46	69	15,770	156	78
	ABLA/CAGE	25,831	1.5	5,021	50	50	5,021	50	50	5,021	50	50
	ABLA/VAGL-VAGL	18,539	1.1	0	0	0	0	0	0	0	0	0
	ABLA/CACA-CACA	15,011	.9	9,310	143	45	9,310	143	45	7,950	137	42
	ABLA/CACA-GATR	4,407	.2	2,262	183	114	2,252	183	114	2,252	183	114
	ABLA/LIBO-LIBO	7,293	.4	4,663	174	109	2,784	168	87	1,665	147	90
	ABLA/VAGL	177,842	10.3	109,829	149	81	109,829	149	71	96,188	148	70
	ABLA/VASC-CARU	19,814	1.1	16,387	161	84	16,287	161	73	16,287	161	70
	ABLA/VASC-VASC	95,405	5.5	79,251	160	101	77,715	169	87	76,592	165	84
	ABLA/CLPS	8,393	.5	8,393	121	120	8,393	121	112	8,393	121	104
	ABLA/ARCO	44,473	2.6	38,554	99	30	38,554	99	29	38,554	99	26
	ABLA/GATR	6,004	.3	6,004	139	80	6,004	139	80	6,004	139	77
	ABLA/GATR-GATR	8,986	.5	7,325	167	84	7,325	167	80	7,325	167	72
	ABLA/LIBO	11,757	.7	0	0	0	0	0	0	0	0	0
	ABLA/VASC-THOC	8,300	.5	0	0	0	0	0	0	0	0	0
Persistent or climax												
	PICO/PUTR	28,871	1.7	28,871	82	59	26,086	83	48	26,086	83	41
	PICO/VACA	22,236	1.3	20,263	171	131	20,263	171	119	20,263	171	115
	PICO/VASC	21,193	1.2	21,193	152	94	1,196	126	88	1,996	126	64
	PICO/CARU	5,599	.3	5,599	60	40	5,599	60	40	5,599	60	40
Other												
	Scree	17,685	1.0	0	0	0	0	0	0	0	0	0
	Nonforested	51,541	3.0	25,993	28	10	25,993	28	10	19,597	6	5

[1]Basal area.

Table 6.—Successional role of lodgepole pine by habitat type (h.t.)—Flathead National Forest

Successional role	H.t. abbreviation	H.t. area on NF		Stands where ≥20% of BA is in LPP exceeding following sizes: LPP >5" d.b.h.			LPP ≥7" d.b.h.			LPP ≥8" d.b.h.		
				Acres	Mean BA[1]	Mean LPP BA[1]	Acres	Mean BA[1]	Mean LPP BA[1]	Acres	Mean BA[1]	Mean LPP BA[1]
		Acres	*Percent*		*Ft²*			*Ft²*			*Ft²*	
Minor seral												
	PSME/VAGL–ARUV	4,199	0.28	0	0	0	0	0	0	0	0	0
	PSME/AGSP	1,549	.10	0	0	0	0	0	0	0	0	0
	PSME/CAGE	500	.03	0	0	0	0	0	0	0	0	0
	TSHE/CLUN–CLUN	1,861	.12	0	0	0	0	0	0	0	0	0
	ABLA/CLUN–ARNU	39,011	2.60	0	0	0	0	0	0	0	0	0
	PSME/ARUV	521	.03	521	160	80	521	160	80	521	160	80
	ABGR/ARNU	34,993	2.33	0	0	0	0	0	0	0	0	0
	THPL/CLUN–CLUN	57,895	3.86	30,854	77	27	6,854	56	33	283	40	40
	THPL/CLUN–ARNU	3,880	.26	1,170	147	40	0	0	0	0	0	0
	ABLA/OPHO	21,463	1.43	3,282	33	11	3,282	33	11	3,282	33	11
	ABLA/LUHI–MEFE	48,140	3.21	4,812	99	32	4,812	99	26	899	83	20
	PSME/PHMA	3,961	.26	2,641	38	11	0	0	0	0	0	0
	PSME/LIBO–SYAL	10,404	.69	4,851	42	13	0	0	0	0	0	0
	PSME/CARU	34,205	2.28	10,520	112	34	3,621	62	23	3,261	63	23
	PSME/SYAL	943	.06	943	40	40	943	40	40	0	0	0
	PSME/ARNU	5,661	.38	1,862	148	33	0	0	0	0	0	0
	ABGR/XETE	87,287	5.82	1,770	51	50	544	80	80	544	80	80
	ABLA/CLUN–MEFE	147,571	9.83	16,101	162	86	12,479	164	61	7,835	157	62
Major seral												
	PSME/VACA	22,309	1.49	14,242	93	57	11,637	96	53	9,466	99	55
	PSME/CARU	17,534	1.17	2,518	107	63	2,258	103	49	2,258	103	43
	PSME/CARU-PIPO	10,275	.68	0	0	0	0	0	0	0	0	0
	PICEA/LIBO	32,913	2.19	3,954	75	22	741	149	60	741	149	40
	ALBA/CLUN-CLUN	84,312	5.62	28,599	133	72	20,052	132	71	20,052	132	62
	ABLA/CLUN-VACA	7,139	.48	2,632	106	62	2,253	138	79	2,253	138	77
	ABLA/CLUN-XETE	71,171	4.74	12,853	137	80	12,853	137	65	12,853	137	52
	ABLA/LIBO-LIBO	6,526	.43	3,780	110	48	0	0	0	0	0	0
	ABLA/LIBO-VASC	36,208	2.41	11,546	113	58	10,520	127	65	10,520	127	58
	ABLA/MEFE	71,711	4.78	24,813	152	100	24,813	152	91	13,502	152	97
	ABLA/VAGL	53,907	3.59	28,895	128	67	20,615	131	62	19,415	132	57
	ABLA/XETE-VASC	47,551	3.17	26,608	122	65	22,261	158	70	17,158	168	69
	ABLA/VASC-VASC	525	.03	0	0	0	0	0	0	0	0	0
	PSME/VAGL-XETE	15,211	1.01	11,188	118	66	8,606	97	37	3,317	49	17
	PICEA/CLUN-VACA	227	.02	227	69	40	0	0	0	0	0	0
	PICEA/CLUN-CLUN	6,951	.46	4,845	126	44	0	0	0	0	0	0
	ABLA/GATR	1,261	.08	1,261	125	90	1,261	125	70	1,261	125	60
	ABLA/CACA-CACA	6,547	.44	6,006	140	52	1,982	100	33	961	80	26
	ABLA/LIBO-XETE	16,930	1.13	14,324	117	57	5,154	79	34	2,274	109	40
Persistent or climax												
	ABLA/VACA	34,595	2.31	7,591	146	92	7,591	146	84	7,591	146	72
Other												
	Noncommercial forest	310,027	20.66	69,766	69	42	64,331	66	28	40,902	72	30
	Water	4,344	.29	0	0	0	0	0	0	0	0	0
	Nonforested	138,435	9.22	11,360	83	61	11,360	83	21	11,360	83	21

[1]Basal area.

Table 7.—Number of habitat types, and area represented by successional role of habitat types, where lodgepole pine can occur—Gallatin N.F. and Flathead N.F., 1975

Lodgepole pine successional roles	Gallatin N.F. H.t.'s	Gallatin N.F. Area		Flathead N.F. H.t.'s	Flathead N.F. Area	
	No.	*Acres*	*Percent*	*No.*	*Acres*	*Percent*
Minor seral						
A. Accidental or sparse	8	227,134	13	10	156,117	10
B. Major component	10	465,582	27	8	290,032	19
Major seral						
A. Sometimes a major component	7	151,560	9	13	462,081	31
B. Usually a major component	11	421,078	24	5	47,127	3
Persistent or climax						
A. Persistent	0	0	0	1	34,595	2
B. Climax	4	78,899	4	0	0	0

Table 8.—Percentage of forest land by successional role and basal area stocking in lodgepole pine 5 to 8 inches d.b.h. in 1975

Successional role	Gallatin N.F. LPP stocking, 5 – 8″ d.b.h.			Flathead N.F. LPP stocking, 5 – 8″ d.b.h.		
	21 – 40% BA	41 – 60% BA	>60% BA	21 – 40% BA	41 – 60% BA	>60% BA
Minor seral	1.4	0	1.7	1.7	0	1.2
Major seral	.5	0	6.6	2.1	2.0	7.1
Persistent or climax	1.7	0	0	0	0	0

Table 9.—Percentage of forested land by successional role and basal area stocking in lodgepole pine >8 inches d.b.h. in 1975

Successional role	Gallatin N.F. LPP stocking, >8″ d.b.h.			Flathead N.F. LPP stocking, >8″ d.b.h.		
	21 – 40% BA	41 – 60% BA	>60% BA	21 – 40% BA	41 – 60% BA	>60% BA
Minor seral	9.5	2.6	0	1.0	0	0.1
Major seral	3.2	15.0	0.9	1.3	6.2	1.0
Persistent or climax	0	[1]1.6	[1]1.5	0	.5	0

[1]Occurs on single district where it comprises about 15 percent of forested area.

Table 10.—Preferred silvicultural systems for managing major damaging organisms

Damage agent	Applicable cover types[1]	Highly susceptible stand characteristics	Preferred silvicultural systems[2]
Western spruce budworm	Douglas-fir Spruce Subalpine fir	Pure stands of tolerant tree species, overstocked, mature multistoried stands.	CC, ST, SHEL
Mountain pine beetle	Lodgepole pine (especially at lower elevations)	LPP trees greater than 8 inches d.b.h. and older than 80 years in pure stands.	CC, ST, SHEL
	Ponderosa pine	Pure even-aged PP, 50-100 years, 8-12 inches d.b.h. Greater than 150 ft^2/acre, slow growing, live crown ratios less than one-third.	CC, ST, SHEL, SEL
Other bark beetles	All	Pure or mixed host tree species in old-growth and stressed stands.	CC, ST, SHEL, SEL
Dwarf mistletoes	Lodgepole pine	Host tree species, multistoried or pure stands, poor vigor.	CC
Root diseases	Douglas-fir	Pure host tree species.	CC
White pine blister rust	Whitebark pine Limber pine	Pure or mixed host tree species. *Ribes* undergrowth.	CC, ST, SHEL
Comandra rust	Lodgepole pine	Pure host types near natural openings.	CC

[1]Forest survey cover types.
[2]CC = clearcut; ST = seed tree; SHEL = shelterwood; SEL = selection.

Table 11.—Acreage and percentage of National Forest in 1975 having susceptible-size lodgepole pine stands, by successional role, with general silvicultural alternatives for reducing future losses

Successional role	D.b.h. size class	Gallatin National Forest		Flathead National Forest		General silvicultural options
	Inches	*Acres*	*Percent*	*Acres*	*Percent*	
Minor seral	5 – 8	53,700	3.1	43,520	2.9	Intermediate thinning, species discrimination; sanitation cuts, clearcut predominantly LPP stands, regenerate other species; partial cutting of larger LPP, where adequate stocking of other species occurs; develop species, age, and stand – size mosaic.
	>8	209,600	12.1	16,510	1.1	
Major seral	5 – 8	122,990	7.1	168,100	11.2	Stocking control thinning, intermediate thinnings; species discrimination where possible; clearcut or shelterwood cut mature stands; regenerate mixed species; manage future stand for short rotation (≅80 years); develop age-class and stand-size mosaic.
	>8	330,860	19.1	127,560	8.5	
Persistent or climax	5 – 8	29,450	1.7	0	0	Stocking control thinning, intermediate thinnings; clearcut mature stands, manage future stand for short rotation (≅80 years); develop age-class and stand size mosaics.
	>8	53,700	3.1	7,500	0.5	

Minor Seral Successional Role

Accidental or minor stand component.—Habitat types where lodgepole pine plays only a minor seral role in succession and generally only occurs as an accidental or minor part of the stand are obviously not a significant mountain pine beetle management problem. The eight such habitat types on the Gallatin National Forest comprise 227,134 acres (91 919 ha) or 13 percent of the Forest (table 7). On the Flathead National Forest there are 10 such habitat types, comprising 156,117 acres (63 179 ha) or 10 percent of the nonwilderness areas of that Forest (only nonwilderness areas were sampled in the Flathead forest inventory).

Major stand component.—There are also habitat types where lodgepole pine plays a minor seral role in succession but can be a major component of stands less than 100 to 120 years of age. Ten of these habitat types comprise 465,582 acres (188 418 ha) or 27 percent of the Gallatin Forest compared to eight on the Flathead National Forest, where 290,032 acres (117 374 ha) or 19 percent of that Forest is involved (table 7). The mountain pine beetle can cause serious damage to stands in these habitat types where the stocking of susceptible-sized lodgepole pine trees is greater than 20 percent of stand basal area. Susceptible acreage on the Gallatin Forest in this successional role is about 263,300 acres (106 554 ha), or a little more than half the area in the 10 habitat types involved. The Flathead Forest has only about 60,000 acres (24 280 ha) of susceptible stands in this successional role, about one-fifth the area of the eight habitat types involved. Fortunately, the species alternatives in this successional role provide three effective silvicultural options for reducing losses to the beetle, depending on the age, form, and species composition of specific stands: (1) clearcut harvesting with regeneration to species other than lodgepole pine; (2) early thinning with discrimination against lodgepole pine; and (3) partial cutting of larger lodgepole pine from overstories where other species in the overstory and understory constitute a manageable stand.

Major Seral Successional Role

When stands are dominated by lodgepole pine where it can play a major seral role, they will eventually become vulnerable to mountain pine beetle depredation if left to develop naturally. If or when they contain appreciable proportions of trees more than 8 inches (20 cm) d.b.h., they will be highly susceptible to infestation at any time that the other conditions for epidemics occur. In these stands, outbreak prevention is largely a matter of removing the stands, or the larger lodgepole pine component, before they become highly susceptible. To accomplish such prevention while maintaining other resource values, a comprehensive long-term plan for scheduling harvests and regeneration is necessary. In regenerating these stands, usually by clearcutting, other species can be featured. In some of these habitat types, Douglas-fir is the major species alternative to lodgepole pine but is itself highly susceptible to spruce budworm (*Choristoneura occidentalis* Freeman) epidemics. In this situation, it is worth considering regenerating the stand with lodgepole pine and managing it for a shorter rotation if another species alternative is not acceptable.

Lodgepole pine sometimes plays a major seral role.—Depending on the circumstances of stand establishment (for example, timing and intensity of wildfires, method of regeneration), there are habitat types where lodgepole pine sometimes is the predominant species of the stands and where succession to climax species will take several hundred years, even in the absence of wildfires.

In the Gallatin Forest, there are seven habitat types where lodgepole pine sometimes plays a major seral role comprising 151,560 acres (61 335 ha) or 9 percent of the Forest. Of this area, only about one-third (3 percent of the Forest) had over 20 percent of stand basal areas in vulnerable-sized lodgepole pine. On the Flathead Forest, there are 13 habitat types where lodgepole pine sometimes plays a major successional role. These habitat types occupy 462,081 acres (187 001 ha) or 31 percent of the nonwilderness area of the Forest; however, of the total 462,081 acres (187 001 ha), only about one-third (10 percent of the Forest) had over 20 percent of the basal area in lodgepole pine of vulnerable size.

Lodgepole pine usually plays a major seral role.—There are considerable acreages where lodgepole pine usually plays a major seral species role because it is usually a dominant component of the stand. On the Gallatin National Forest, there are 11 habitat types where this situation prevails. They comprise about 421,078 acres (170 407 ha) or 24 percent of the Forest, with about 70 percent of this area (286,115 acres [115 789 ha]) occupied by stands having from 30 to 60 percent of their basal areas in lodgepole pine trees of 8 inches (20 cm) d.b.h. and larger. On the Flathead National Forest, there are only five habitat types and 47,127 acres (19 072 ha) or 3 percent of the Forest where lodgepole pine is usually a major seral species involving 30 to 60 percent of stand basal area in lodgepole pine trees more than 8 inches (20 cm) d.b.h.

Stands in the habitat types where lodgepole pine usually plays a major seral role and that have over 20 percent of their basal areas in larger lodgepole pine trees are very vulnerable to the mountain pine beetle—especially if they are older than 80 years. In these habitats, if stands are less than 200 years old, the overstory is usually dominated by lodgepole pine or the stand is pure lodgepole pine. If the stands are younger than 80 years, they should (in consideration with all other lodgepole pine stands) be scheduled for harvest at somewhere around 80 years of age, or perhaps the rotation extended by thinning on a schedule to maintain stand growth. In practical terms, most 80- to 100-year-old natural stands in this successional situation do not have a large component of high-hazard trees because most were established by wildfires that resulted in serious overstocking. When this is the case, significant basal areas of vulnerable tree size do not usually occur until stands reach ages of 140+ years.

Persistent seral or climax successional role.—There appear to be no habitat types where lodgepole pine is a persistent seral species on the Gallatin Forest; however, there are considerable acreages of habitat types where lodgepole pine is a virtual climax species and expresses

itself in essentially pure stands. Four habitat types of the *Pinus contorta* series occur on the Gallatin and involve 78,899 acres (31 925 ha) or 4 percent of the Forest. The typical basal area of these stands, in trees 8 inches (20 cm) d.b.h. and more, ranged from 48 to 67 percent of the total stand basal areas. Younger stands, of course, have lower basal areas of susceptible-sized trees, but the oldest natural stands in these habitat types do not greatly exceed these basal area proportions of susceptible-sized trees because the mountain pine beetle periodically reduces the stocking of larger trees. The result is two- or three-story stands of trees of different age and size classes. The overall effect is likely to be more chronic infestations by the beetle because of a more constant food source. Beetle infestations in each stand may result in fewer trees being killed during each infestation than would occur in even-aged stands developed after fires and in those stands where lodgepole pine is seral. Managers should take these factors into consideration when reviewing and prescribing silvicultural alternatives for this situation.

On the Flathead National Forest, no habitat types exist where lodgepole pine has a climax role in succession; however, there is one habitat type (*Abies lasiocarpa/Vaccinium caespitosum*) where lodgepole pine is a persistent seral species dominating stands. It occupies only about 2 percent of the Forest (34,595 acres [14,000 ha]), and of this only about one-fifth (7,000 acres [2 833 ha]) has greater than 20 percent of its basal area in susceptible-sized trees. Thus, the persistent or climax role is less of a concern on the Flathead than on the Gallatin.

EFFECTS OF OUTBREAKS AND MANAGEMENT RESPONSES ON BIG GAME AND OTHER WILDLIFE

Jerome T. Light
Gallatin National Forest
Bozeman, MT

William B. Burbridge
Wildlife and Fisheries
Intermountain Region
Ogden, UT

Lodgepole pine forests provide habitat for big game wildlife such as the Rocky Mountain elk (*Cervus canadensis*), mule deer (*Odocoileus hemionus*), grizzly bear (*Ursus arctos horribilis*), and numerous small game and nongame species. An approach for integrating wildlife habitat requirements with stand management of lodgepole pine forests has been addressed in general terms (Thomas 1979). But the management of big game, especially during hunting seasons, has assumed increasing importance as forest cover is reduced and human access increases. Such management is a growing concern of many State fish and game agencies (Lonner and Cada 1982). As a result, timber management in lodgepole pine, particularly harvesting and associated roading, often creates considerable controversy regarding effects on big game. The occurrence of and potential for mountain pine beetle outbreaks add greater complexity to these controversies. This section describes the effects on stands, and thus on big game and other wildlife, of epidemics left to occur and recur naturally and discusses alternative silvicultural responses for preventing or reducing beetle outbreaks in terms of how these practices affect habitat and other management concerns for big game and other wildlife.

Silvicultural practices to meet wildlife management objectives should encompass (1) scheduling of treatments, (2) distribution of stand age classes in time and space, (3) stand condition desired, (4) size of treatment area, and (5) the habitat characteristics (cover/forage) of the land type to be affected by the treatment. It is interesting to note that meeting wildlife management objectives will often make the forest less susceptible to damage from the mountain pine beetle.

The stand/beetle/silviculture interactions are discussed in relation to wildlife effects for species groups of major wildlife management interest:

- Elk and mule deer
- Whitetailed deer and moose
- Grizzly bear
- Other wildlife

Rocky Mountain Elk and Mule Deer

Beetle epidemics can affect elk and mule deer by altering the arrangement and abundance of food, cover, and other key components of habitat, thus altering wildlife use patterns. Management activities to prevent or reduce beetle effects also influence these factors, as well as increase human disturbance through management activities and roading.

In some habitat types where other species are well represented, recurring bark beetle epidemics have helped maintain wildlife habitat diversity of unmanaged stands. However, with this increased diversity is an associated increase of dead wood accumulation on the forest floor which can inhibit elk and deer use (Lyon and Jensen 1980) and eventually dispose the area to a stand replacement fire.

Biological effects of beetle epidemics and timber management on elk and deer depend largely upon the relationship between the abundance and arrangement of forage and cover. Optimum summer habitat for elk consists of a ratio of 40 percent cover and 60 percent openings, properly sized and arranged in space (Black and others 1976) (fig. 61). These authors further recommended that cover areas consist of approximately 20 percent hiding, 10 percent thermal, and 10 percent either hiding or thermal cover on big game summer range (figs. 62 and 63). If big game are to make maximum use of forage areas, no point should be more than 600 ft (183 m) from the edge of cover; use beyond that distance declines steadily (Reynolds 1962, 1966; Harper 1969; Kirsh 1962; Hershey and Leege 1976).

Having determined the consequences of beetle epidemics on elk and deer habitat as well as other resource values, managers should review and select silvicultural alternatives for reducing or preventing these consequences. Clearcutting appears to be the most desirable

Figure 61.—Optimum summer range for elk contains approximately a 40:60 ratio of cover and forage. When these situations occur naturally, there is potential for degradation of summer range from beetle epidemics and management responses to them.

Figure 62.—Regeneration harvests should not be initiated in leave strips until adjacent cut-over areas provide hiding cover or if the leave strips are needed for thermal cover. This lodgepole pine regeneration does not appear to provide hiding cover.

Figure 63.—This lodgepole pine regeneration appears to provide suitable hiding cover.

silvicultural system for preventing or reducing losses to the beetle and for creating forage areas for big game. If the stand is already at cover/forage limits for big game, then other prescriptions should be considered.

At any time before epidemic outbreaks and where stands have been hazard-rated, group selection cuts might be made in a pattern favorable for both preventing losses to the beetle and enhancing wildlife habitat. In younger stands, initial and intermediate thinnings can be used to reduce future stand susceptibility to the beetle. Likewise, in older stands with a manageable component of other species, the larger lodgepole pine can be harvested. The farther in advance of epidemics these preventative measures are implemented, the more significant their impact on wildlife habitat.

Edgerton (1972) found that clearcutting in mixed conifers in northeastern Oregon benefited forage for elk and deer, with elk preferring clearcuts as feeding sites almost twice as much as unlogged areas. Deer displayed essentially the same order of preference as elk, but to a smaller degree (fig. 64).

Clearcutting in lodgepole pine was shown to stimulate the production of understory vegetation for an estimated 20 or more years, providing a grazing resource for big game and livestock in Montana with peak productivity at 11 years (Basile and Jensen 1971). Similarly, Wallmo (1969) found that mule deer use in Colorado doubled 10 years after logging in clearcut lodgepole pine and spruce/fir types, as compared to previous use.

Silvicultural practices that clear or open lodgepole pine stands increase forage for elk and deer, depending upon stand structure and composition, but the availability to elk and deer depends on slash treatment. Lemos and Hines (1974) found that slash accumulations inhibited forage production and restricted its availability to elk and deer. Lyon (1976) also found that elk use of clearcuts was influenced by slash accumulation inside and adjacent to the affected openings. Slash depths greater than 1.5 ft (45.7 cm) significantly reduced elk utilization of foraging areas. Slash disposal can cause additional problems, however. Broadcast burning of slash rather than machine piling and burning is the preferred method of disposal because, as Pengelly (1972) observed, the mechanical disturbance of soil by heavy equipment combined with the burning of piles tended to eliminate some desirable forage species. Harper (1971) and Lemos and Hines (1974) also found that broadcast burning of slash is more advantageous for big game. Broadcast burning removes physical barriers, promotes sprouting of desirable shrubs, encourages the establishment of a greater diversity of forbs and grasses, releases nutrients, and often retards succession, providing forage over an extended period of time.

Forage in clearcut openings during the winter is usually unavailable to big game due to deep-crusted snow. On elk and deer winter range where winds do not influence snow depth, clearcutting in response to beetle epidemics generally results in loss of cover and no gains in available forage. Uneven-aged stands with small openings favor both elk and deer winter forage and cover requirements (Wallmo and Schoen 1981). To avoid wholesale loss to the mountain pine beetle of winter cover in historical winter range, lodgepole pine stands should come under long-term management from the regeneration process onward so that needed cover is maintained.

The alteration of key habitat components of elk and deer requires special consideration by forest managers,

Figure 64.—Clearcutting is usually the most desirable silvicultural system for creating forage areas for both deer and elk in mixed conifer forests.

as these key areas contribute significantly to the carrying capacity of a given area. The Montana Cooperative Elk-Logging Study (1978) reported that moist sites (wet sedge meadows, bogs, seeps), especially those located at the heads of drainages (fig. 65), are important components of elk summer range. These sites provide lush, nutritious forage for elk late into the summer (fig. 66), enabling them to move to winter range in better condition. These sites also are important breeding areas for elk (fig. 67) and are used for wallowing.

Moist sites receive disproportionately higher use given their relative size. Other key areas include winter range with nearby thermal cover (fig. 68) and calving and rearing areas (fig. 69).

Silvicultural prescriptions, including those designed to prevent beetle effects on wildlife habitat, should be designed to maintain the integrity and value of all key areas. Areas adjacent to moist sites, breeding areas, and reproduction areas should remain in cover to provide cover linkages with the uncut forest. Whenever practical, disturbance of these sites should be avoided during the rut through the use of timber sale contract clauses and road closure.

Perry and Overly (1977) conducted research to determine the biological effects of roads on elk and deer. Wildlife biologists and forest managers recognize road management as one of the most important aspects of elk management. Allen (1977) concluded that roads or other human disturbances could be more significant in evaluating the effectiveness of elk habitat than vegetative manipulation. Ward (1976) and Perry and Overly (1977) reported decreased elk use adjacent to open roads for distances ranging from one-fourth to one-half mile (0.4 to 0.8 km). Rost and Bailey (1979) found that deer and elk in Colorado avoided areas within 10 chains (201 m) of roads and avoided roads in shrub zones more than in the

Figure 65.—Moist sites, particularly those at the heads of drainages, are used by elk for wallows and are important components of elk summer range.

Figure 66.—Optimum elk summer habitat should consist of approximately 60 percent foraging areas which are properly arranged in time and space.

Figure 67.—Wet areas such as this have been identified as important components of elk summer range and should be protected.

Figure 68.—Protection of winter range and nearby thermal cover are important considerations in silviculture prescriptions and road layout.

Figure 69.—Key habitat components such as elk calving areas should be maintained through proper silvicultural prescriptions. Human activity should be restricted in calving areas during the spring and early summer.

ponderosa pine zone. These data are comparable to those of Lyon (1979), who concluded that the impacts from open roads were greatest where cover was low. Cover modification and roading can affect hunting opportunities and the variety of hunting experiences, thus affecting levels of game harvest (Lonner and Cada 1982). Hunting conditions are affected most significantly by the density of open roads. Cover availability and the density of open roads can also influence season lengths and the number of hunting recreation visitor days.

Moose and Whitetailed Deer

Moose (*Alces alces*) and whitetailed deer (*Odicoileus virginianus*) are primarily browsers of deciduous shrubs; however, moose browse evergreen (spruce and fir) saplings in addition to deciduous shrubs and herbaceous plants. Their cover requirements seem to be more restrictive than those of elk and mule deer (Peek and others 1983). Vertical structure of stands and snow structure are critical factors to consider for moose and deer on winter range. In southwestern Montana, Schladweiler (1973) found that the Shira's moose responded positively to clearcuts the first year in lodgepole pine stands, with use peaking 10 years after harvesting. This is most noticeable where clearcut stands develop an understory of shrubs providing both forage and cover. Whitetailed deer respond similarly. Schladweiler (1973) and, in southeastern Idaho, Ritchie (1978) found that moose use was greatest in habitat types providing high densities of understory shrubs in both mature and postlogged forest conditions. Both moose and whitetailed deer were found to favor stand characteristics that provide small openings with both thermal and hiding cover. Engelmann spruce/alpine fir and alpine shrub understories are preferred by moose (Schladweiler 1973; Ritchie 1978). In uneven-aged stands with small openings, evergreen saplings and deciduous shrubs are usually most available as browse.

Grizzly Bear

The grizzly bear is a federally classified threatened species. Grizzlies once ranged throughout most of the Western United States; however, fewer than 1,000 are now estimated to exist in the lower 48 States. This population is distributed among three major ecosystems: the Yellowstone, the Northern Continental Divide, and the Cabinet-Yaak. Lodgepole pine provides the dominant cover for the grizzly within all of these ecosystems. Mountain pine beetle infestations and timber management practices to reduce the risk and spread of infestation can, therefore, affect grizzlies by changing their habitat use patterns, food availability and abundance, and security.

Grizzly habitat use patterns may be modified by vegetational changes affecting cover and food availability. A major food source—whitebark pine nuts—was all but eliminated by epidemic infestations in whitebark pine stands in portions of the Beaverhead, Flathead, and Gallatin National Forests. On the Flathead National Forest, such a loss of the whitebark pine resulted in the breakdown of a historical grizzly bear use pattern (Servheen 1981). Food production (for example, berry and herbaceous foods) may be increased through timber management (Ruediger and Mealey 1978) causing bears to immigrate.

Ruediger and Mealey (1978) recommend that at least 30 percent of grizzly habitat be managed as cover. Decreasing the amount of cover can have either positive or negative effects on bear habitat suitability. If cover is determined to be limiting, either in relative amount or distribution, beetle epidemics or timber harvesting will probably have a negative impact on the grizzly bear. Where cover is abundant, however, epidemics or timber harvest can improve the abundance and/or distribution of forage; hence, the consequences will probably be positive for the grizzly.

In view of the grizzlies' need for forest cover, it would be better in some areas to reduce the potential for epidemics in critical grizzly habitat where stand management options are still allowed, especially where stand management or diversity of an even-age class will not adversely affect the grizzly.

Grizzlies derive most of their energy from whitebark pine nuts and succulent herbaceous plants from mesic microsites in forest stands and mountain grasslands (Mealey and others 1977) (fig. 70). Grizzlies west of the Continental Divide derive most of their energy from huckleberries and whitebark pine nuts. When berry production trends are up west of the Divide, grizzlies derive most of their energy from the sugars the berries provide. East of the Divide, energy is derived mainly from succulent plants, carrion, insects from downed logs and anthills, and parts of specific plants such as spring beauty, elk thistle, biscuitroot, and clover (Ruediger and Mealey 1978). Since the grizzly spends all of its time eating in or close to the cover of forest stands (Blanchard 1980), timber management in roaded areas should be oriented to maintaining cover corridors for day bedding and travel security.

The grizzly bear's precarious situation can primarily be attributed to human encroachment and the loss of the large roadless areas which were once prime grizzly habitat. Development of these areas has adversely impacted the bear by increasing encounters with humans, which often have resulted in death for the grizzly. In the Yellowstone ecosystem, there is concern that mortality may still exceed recruitment; therefore, reducing bear mortality is probably the single most important task for recovering the grizzly bear population. This can be helped by developing management systems which minimize human encounters with grizzlies. Rigorously enforced road and trail regulations are important for accomplishing this objective.

Timber management without road and trail management has usually provided the initial inroad for humans into otherwise secure grizzly habitat. We suggest, then, that roads constructed to prevent or mimimize future epidemics or for other necessary management activities in grizzly-occupied habitat should be managed (closed if necessary) as soon as administrative use allows.

Figure 70.—The grizzly is an aggressive opportunist and will capitalize on all available forage items in its home range.

Figure 71.—The northern three-toed woodpecker is a common primary cavity user in lodgepole pine forests and is one of the natural control agents for keeping mountain pine beetle populations at endemic levels.

Other Wildlife

Mountain pine beetle epidemics and management activities to prevent or reduce them can affect many other species of wildlife. Although it is not possible to give direct attention to each species, forest managers should provide habitat conditions that will maintain viable populations of all wildlife. This can be achieved by modifying silvicultural practices to provide a broad spectrum of habitat conditions (Thomas 1979). This includes maintaining special habitats such as riparian zones, edges, snags, and dead and downed woody material.

Timber management may produce successional conditions that mimic wildlife habitat conditions produced by natural events such as wildfire. Maintenance of viable populations of wildlife is most heavily influenced by the maintenance of areas of early (grass/forb and shrub/seedling) and late (mature and old growth) forest successional stages (Thomas 1979). Management to minimize or prevent beetle outbreaks, therefore, should be designed to provide the amount and variety of habitat for viable populations of desired wildlife species.

Snag management for cavity nesting birds (fig. 71) is an important facet of managing lodgepole pine forests because of the many snag-dependent species which prey on harmful insects.

Hein (1980) suggests leaving an average of two snags per acre (five snags/ha) in managing lodgepole pine forests. Thomas and others (1978) recommend leaving an average of 0.6 snags per acre (1.5/ha) as a minimum to ensure viable populations of cavity-dependent species. Snags more than 10 inches (25.4 cm) d.b.h. with broken tops should be given priority when selecting snags to leave (fig. 72).

Figure 72.—Snags with broken tops receive higher use from cavity-dependent species and should be emphasized for retention.

Because most birds in the lodgepole pine communities glean insects from bark and foliage, bird management should be an important consideration as a possible means of maintaining beetle populations at endemic levels.

SOIL AND WATER QUALITY

Mark D. McGregor
Cooperative Forestry and Pest Management
Northern Region
Missoula, MT

The effect of mountain pine beetle epidemics on water quality and quantity and the overall effect on watersheds are not well known. Effects might be minimal in some drainages but of more concern in others. The degree of increased water yield depends largely on the amount of lodgepole pine in the stand, soil type and depth, the amount of snow intercepted by the original stand, and how rapidly understory vegetation uses the increased soil water.

Removal of infested trees, and thus creation of openings, can increase melt rates and peak runoff. An extensive number of large clearcuts could create the potential of floods—increasing channel changes and erosion. In this case, up to 50 years may be required before watershed recovery following vegetation reestablishment.

Stands of dead trees would increase soil moisture and subsequent yields from the watershed. These trees also provide some reduced shading cover, intercept rain and snow, and protect soil through holding soils in place with roots.

The primary watershed concerns with epidemics thus appear to be the potential for lowering water quality through sedimentation from roads constructed to salvage timber and the loss of shade, which can elevate water temperatures to levels detrimental to fish. Nutrient losses can also occur with erosion, to the detriment of biological processes.

In harvested stands, proper slash disposal and site preparation can provide organic matter and dead shade and maintain soil protection.

Soil disturbances on sites with soils subject to frost heaves could further degrade the sites and add to stream siltation. These soils are generally shallow and thus have low moisture storage capacity. This, plus exposure, leads to overland flow and high runoff. Slash can entrap silts and retard surface flows and thus help maintain site fertility (Carter 1978).

Appropriate silviculture can be achieved by consulting available specific guidelines that address concerns about maintaining soil stability and water quantity and quality (Leaf 1975; Singer and Maloney 1977). These guidelines should be consulted in designing specific management prescriptions.

LANDSCAPE AND VISUAL MANAGEMENT CONCERNS

Mark D. McGregor
Cooperative Forestry and Pest Management
Northern Region
Missoula, MT

Mountain pine beetle epidemics leave many acres of lodgepole pine dead or dying and have a negative visual effect. This is apparent even in stands that have considerable amounts of other species. From a visual perspective, the more rapidly the dead lodgepole pine is replaced with healthy vegetation, the better (Carter 1978); however, if cutting methods selected for natural regeneration or to minimize losses are visually more undesirable than the effect of standing and fallen dead timber, the visual discontinuity of the landscape will have been aggravated or even magnified instead of lessened (Carter 1978). Such negative elements should be identified along with positive elements of visual form that can be emphasized. Both the negative and positive elements of existing or future landscapes should be considered within the perspective of "desired landscape character" to attain visual quality objectives. Visual quality objectives (VQO's), desired landscape character, and positive and negative landscape elements are concepts used to analyze and manage landscapes in the National Forest system. They are being used to address landscape concerns in many complex resource management situations. A specific example involving the mountain pine beetle was the Lane-Peet Study conducted by the Umatilla and Wallowa-Whitman National Forests in northeastern Oregon (Umatilla National Forest 1974). From this effort came six recommendations for minimizing visual impairment of landscapes from management responses to the mountain pine beetle (Carter 1978):

1. Avoid sharp-edged rectangles or other geometric patterns when laying out cutting units. Units should also vary in size, thus repeating the variety of meadow and opening sizes that occur in nature. Unit sizes could vary from 4 to 60 acres (1.6 to 24.3 ha).
2. Leave trees in shelterbelt units in groupings instead of rows to eliminate the straight line effect.
3. The location of roads should be as well planned as in green sales, with thought given to such things as minimum clearing widths.
4. Fill slopes and ditches along system roads, especially in unstable, light-colored soil areas, should be seeded immediately to appropriate grasses. Temporary spurs should be seeded as soon as salvage operations cease.
5. A "dead screen" may be useful in slowing down or stopping the eye as it travels over or through large open spaces created by the salvage activities. It is understood that the dead trees will need to be managed as they begin to fall.
6. Existing regeneration groupings should be used as screens wherever possible. Landings may be screened from a major travel route, even though most of the sale area is not.

Although some of the above recommendations are pertinent to silvicultural practices used to prevent mountain pine beetle epidemics, it is clear the emphasis of the recommendations is to ameliorate the visual effects of epidemics after the fact. It is beyond the scope of this paper to address landscape management in the preventative sense of mountain pine beetle/lodgepole pine management because of the complexities of social, economic, and biological factors involved. Readers should consult USDA Handbook No. 559, Vol. 2, Chap. 5 (Bacon and Twombly 1977), a valuable management guide for these purposes.

COORDINATING MANAGEMENT OBJECTIVES WITH SILVICULTURAL SYSTEMS AND PRACTICES

ACCEPTABLE SILVICULTURAL SYSTEMS IN RELATION TO DESIRED STAND CHARACTER AND SUCCESSIONAL ROLES OF LODGEPOLE PINE

Dennis M. Cole
Intermountain Forest and Range Experiment Station
Forestry Sciences Laboratory
Bozeman, MT

All lodgepole pine stands in a management jurisdiction, regardless of habitat type—but especially where the successional role of lodgepole pine is dominant seral, persistent, or climax—must be considered together to develop a long-range plan for increasing age-class and species diversity of the future forest. Summaries such as tables 5 to 9 and 11 will be helpful in this effort.

Such information can also be used with recently developed criteria for identifying appropriate silvicultural systems for managing multiple resources (USDA Forest Service 1980, p. 87) and with various published guidelines for a variety of management concerns. Among these are guides for regeneration (Lotan and Perry 1983); fire ecology (Fischer and Clayton 1982); dwarf mistletoe infection (Hawksworth and others 1977; Van Sickle and Wegwitz 1978); windfall risk (Alexander 1975); watershed considerations (Leaf 1975); scenic values (Bacon and Twombly 1977); and wildlife values (Thomas 1979; Perry and Overly 1977; Lyon and O'Neil 1981; Ruediger and Mealy 1978; Hein 1980).

As an example of how information from tables 5 to 9 and 11 can contribute to better plans for achieving allocated resource management objectives, consider a recent management analysis conducted while preparing the Forest Plan for the Gallatin National Forest (Gilbert and others 1980). This analysis was guided by three principles of policy: (1) the concept of "desired character of stand" was adopted as the means of identifying appropriate silvicultural systems for achieving allocated resource management objectives; (2) uneven-aged silvicultural systems would only be considered when timber is not included in resource management objectives; and (3) five silvicultural/management criteria (USDA Forest Service 1980) were adopted as the basis for choosing acceptable silvicultural systems.

The five criteria were:

1. The (silvicultural) system must develop stand conditions required for meeting allocated resource management objectives over the longest possible time.
2. The (silvicultural) system must permit enough control of competing vegetation to allow establishment of an adequate number of trees growing at acceptable rates.
3. The (silvicultural) system must promote stand structures, compositions, and conditions that minimize damage from pest organisms, animals, wind, and fire.
4. The (silvicultural) system must be compatible with acceptable logging methods so that future stands produced can be cultured and harvested.
5. Uneven-aged silviculture will be considered only where stands presently have a homogenous uneven-aged structure or where steps and the time necessary for conversion to an identifiable uneven-aged goal can be defined.

From the above principles and criteria, the Gallatin Forest team identified important regeneration problems and keyed them to the character of competing vegetation and topographic aspect (table 12); defined classes of desired stand character and identified preferred (acceptable) silvicultural systems for achieving each in the lodgepole pine cover type (table 13); and identified preferred

Table 12.—Selection of silvicultural system based on common regeneration problems on the Gallatin National Forest

Competing vegetation	Key habitat series or type	Critical aspect	Preferred system: Even-aged	Preferred system: Uneven-aged[1]
High-elevation brush	ABLA series; ABLA/ALSI h.t.	All	Clearcut	All selection
Low-elevation brush	PICO, PICEA series; PSME/PHMA, PSME/SYAL, PSME/PUTR h.t.'s	All with slopes >30 percent	Shelterwood Clearcut with artificial regeneration	All selection
Grasses (warm sites)	PIPO, PSME, and ABLA series	All	Shelterwood	Group selection
Grasses (cool sites)	PICO, PSME, and ABLA series	All	Clearcut Seed tree Shelterwood, artificial regeneration	Group selection

[1]Only applicable for resource management objectives other than timber production.

(acceptable) silvicultural systems for handling important damage agents and cross-referenced them to applicable Forest Survey Cover Types and highly susceptible stand characteristics (table 10). Preferred (acceptable) silvicultural systems were also identified in relation to fuels management and logging methods; however, the information of table 5 does not relate well to these management interests, so they are not considered further here.

The identification of general classes of competing vegetation that are associated with regeneration problems and the determination of preferred silvicultural systems for minimizing the problems (table 12) helps the manager, on the ground, to select a proper silvicultural system for successful regeneration when harvest is planned and accomplished. Reference to summaries like table 5 and tables of plant presence, constancy, and coverage (Pfister and others 1977) provides additional information on the acreage and character of habitat types where problems can occur from each of the classes of competing vegetation.

Table 13 lists six different "desired stand characters," with preferred (acceptable) silvicultural systems for attaining each—under both even-aged and uneven-aged management. The manager needs additional information, however, to select the most appropriate "desired stand character" for meeting allocated multiple resource management objectives. This is particularly the case for the lodgepole pine type and habitat types where lodgepole pine is represented, because of the management complications wrought by the mountain pine beetle. Summaries, such as table 5, of the total habitat-type acreage and of the habitat-type acreage where appreciable basal area of the stand is in lodgepole pine in sizes susceptible to the mountain pine beetle can help the manager select the stand character that will best serve the various resource values he or she considers important. From such summaries, he or she can also determine where, and to what extent, the various "desired stand character" alternatives are attainable and maintainable. For each habitat type, other information for determining "desired stand character," which can be used in conjunction with the summaries, can be found in lists of plants, along with their constancy and average coverage values. These lists are included in published habitat type classifications (Pfister and others 1977).

Table 13.—Preferred silvicultural system to achieve desired lodgepole pine forest character

Desired character	Preferred silvicultural system: Even – aged	Uneven – aged[1]
Continuous site occupancy with trees	Shelterwood	Single tree selection
Mosaic of forest and opening	Clearcut, seed tree, shelterwood	None
Multistoried stand (all components less than rotation)	Clearcut, seed tree, shelterwood	Single tree and group selection
Maximum species diversity	Shelterwood	Group selection
Old growth character	Shelterwood	Single tree and group selection
Closed canopy	Clearcut, seed tree, shelterwood	None

[1]Only applicable for resource management objectives other than timber production.

SILVICULTURAL PRACTICES FOR LODGEPOLE PINE STANDS IN COMMERCIAL FORESTS

Dennis M. Cole
Intermountain Forest and Range
Experiment Station
Forestry Sciences Laboratory
Bozeman, MT

Mark D. McGregor
Cooperative Forestry and Pest Management
Northern Region
Missoula, MT

By knowing the area, composition, form, structure, age, habitat type, and successional role of each lodgepole pine stand occurring on a District or Forest, administrators can make computer simulations to preview time and scale effects of appropriate silvicultural systems and practices on these characteristics of the future forest. The different computer-generated stand and forest scenarios can then be evaluated for various resource concerns and susceptibility to the mountain pine beetle using the information of these guidelines. Evaluations of successional roles in relation to appropriate silvicultural systems for specific resource allocation objectives of a representative National Forest were presented earlier. Following is a brief review of silvicultural practices for pure and mixed species lodgepole pine stands on lands designated as commercial forest.

Practices for Pure Lodgepole Pine Stands

In pure lodgepole pine stands, valid silvicultural practices for dealing with the mountain pine beetle include (1) stocking control, (2) clearcutting mature stands under a long-term plan to create age, size, and species mosaics, (3) salvage cutting to mitigate losses in stands under attack, and (4) sanitation cutting in some situations.

Stocking control.—Stocking control is an extremely important practice in pure, even-aged lodgepole pine. It promotes good stand vigor and can be used to direct stand growth toward moderate tree size and rotation objectives (D. M. Cole 1978). Initial stocking control (fig. 73) by age 25 (preferably by age 15) to a spacing of 10 or 12 ft (3 or 3.7 m) usually results in culmination of mean annual cubic volume increment on medium-to-good sites at about age 80—with average stand diameters of about 10 inches (26 cm) d.b.h. (D. M. Cole 1975). Stands of this age and structure do not have high risk of mountain pine beetle infestation.

Control of stocking through intermediate thinnings can also reduce the susceptibility of mature and near-mature stands; however, once begun, such thinnings might need to be repeated to maintain stand vigor until harvest. Thinnings repeated to maintain stand vigor will usually be uneconomic in terms of value of volume removed, but might be justified as a loss-prevention practice. Improved vigor of trees in managed stands will prevent infestation by *Ips* spp. and *Pityogenes* sp. and other secondary bark beetles that assist mountain pine beetle populations to survive in unhealthy trees during endemic levels (Schmitz 1984). Nevertheless, managers should consider the possibility of secondary bark beetle populations building up in thinning slash and attacking and killing leave trees. Late summer, early fall, or winter thinning will prevent a population buildup and mortality of leave trees. If dwarf mistletoe is present in stands, it should be considered in leave tree selection since thinning usually intensifies dwarf mistletoe effects.

Figure 73.—Stocking control in a young lodgepole pine stand has resulted in favorable spacing for future growth.

Clearcutting.—Clearcutting in small- to moderate-sized blocks (fig. 74) creates age and size mosaics from extensive, pure lodgepole pine stands and is a highly recommended practice (Roe and Amman 1970; Amman 1976). Timely surveys and maps of stand growth and volume, site quality, dwarf mistletoe distribution—and related factors such as phloem thickness, elevation, stand structures and form, composition, and ecological habitat type—are essential for clearcutting to be effective. Size and shape of clearcuts are extremely important in dwarf mistletoe-infected stands.

Schedules for clearcutting as a preventative measure should be coordinated with other multiple-use management objectives. In areas where probability for loss is high, future damage can be reduced by directing regeneration to alternating species among blocks or to mixed species within blocks (fig. 75) (D. M. Cole 1978). Models for predicting stand growth have been developed for determining the effects of prescribed management activities (Stage 1972; Edminster 1978). Caution is needed, however, in using such models to examine the interaction of the mountain pine beetle and lodgepole pine forests over time.

Figure 74.—Organized block clearcutting can be used to create age, species, and size mosaics from extensive, pure, even-aged lodgepole pine stands.

Figure 75.—Clearcuts regenerated with mixed species and alternating species among blocks.

Salvage and sanitation cutting.—Salvage cutting is defined as the removal of dead, dying, or deteriorating trees damaged by fire, wind, insects, diseases, or other injurious agents; sanitation cutting is the removal of infested trees to prevent the spread of pests or pathogens. Sanitation and salvage cutting should be justified either directly by timber economics or indirectly through protection of other resources to qualify as loss reduction practices (D. M. Cole 1978). Salvage and sanitation cutting should be carefully planned and administered as conscious silvicultural practices to protect other resource values (fig. 76).

Time between tree killing and salvage cutting should be minimal to prevent wood deterioration. Sanitation cutting of infested trees from high-hazard stands may slow disease outbreak, but it must be done before beetle flight or it will not be effective (fig. 77). The cost of repeated entries for sanitation purposes, however, is usually prohibitive, and success depends on timely execution and accurate assessments of hazard and risk.

Figure 76.—Salvaging heavily infested stands through clearcutting and sanitation cutting, as was done in background stand, can provide protection, at least temporarily, for nearby stands where esthetic and other resource values are crucial (North Fork Flathead River drainage, Montana).

Figure 77.—Proper scale, marking, and timing of sanitation cuts are crucial to prevent beetles from seeking out and attacking large-diameter trees in adjacent high-hazard stands. This stand shows spread of beetles after a poorly marked and timed sanitation cut.

Surveys to inventory stand structure and the diameter-phloem thickness distribution of stands can identify high-risk trees for preventative cutting (fig. 78) to forestall beetle infestation for several years.

Sanitation cutting must be carefully coordinated to prevent spread of beetles into other stands along haul roads or from infested logs decked at sawmills (fig. 79). Sanitation cutting must also take into account the factors of windthrow and dwarf mistletoe infection in the residual stand. These factors are dealt with in the discussion of partial cutting in the section on practices for mixed species stands.

Sanitation cutting, as previously described, is, of course, partial cutting for sanitation purposes. Partial cutting of larger lodgepole pine in pure, and particularly even-aged, lodgepole pine stands as a preventative practice should be used sparingly and with caution. Nevertheless, it has application in a couple of situations: (1) where extensive clearcutting has occurred in a drainage and further clearcutting is prohibited by nontimber concerns such as wildlife cover, riparian zones, esthetic values, or watershed values and (2) where the pest manager feels that the spread of infestations can be slowed enough that losses can be prevented or reduced in nearby stands through the use of other practices.

Partial cutting to achieve longer term benefits through species discrimination is discussed in the following section on practices for mixed species stands.

Figure 78.—Removal of high-risk trees in the foreground reduced subsequent infestation levels in this high-hazard stand, West Yellowstone, MT.

Figure 79.—Timely processing of infested logs before beetles emerge from them will prevent infestation of susceptible stands in the area.

Practices for Mixed Species Lodgepole Pine Stands

Mixed species lodgepole pine stands vary greatly in form, proportion, and structure of the lodgepole pine, relative to the other species present. Still, some common expressions of these stand characteristics occur.

A common situation in habitat types of the subalpine fir series is a mature or overmature lodgepole pine overstory with a mixture of smaller shade-tolerant species and some younger lodgepole pine in the understory (fig. 80). The size and mixture of the understory depends largely on the number and size of openings created in the overstory by insects, diseases, and climatic factors (D. M. Cole 1978). This successional situation is common near and east of the Continental Divide, where mixed overstory stands are usually well advanced in succession of Douglas-fir, Engelmann spruce, and subalpine fir, and the lodgepole pine is in a decadent condition (fig. 81).

Figure 80.—Mature overstory of lodgepole pine with mixture of shade-tolerant subalpine fir and some lodgepole pine in the understory.

Figure 81.—Overstory of lodgepole pine with climax understory of spruce and subalpine fir. Lodgepole pine is severely infected with dwarf mistletoe.

Even-aged mixed species lodgepole pine stands also occur. These are usually lodgepole pine-western larch (fig. 82) or lodgepole pine-Engelmann spruce (fig. 83) mixtures where lodgepole pine did not predominate the site in the regeneration process.

Another common situation involves one or more other species in the overstory with lodgepole pine, with an understory of one or more climax species (figs. 84 and 85). This is common west of the Continental Divide in the range of western larch and the ranges of more shade-tolerant species such as Douglas-fir, Engelmann spruce, grand fir, and western white pine.

Stocking control, clearcutting, sanitation cutting, and salvage cutting are acceptable silvicultural practices for mixed species lodgepole pine stands. As with pure lodgepole pine stands, the applicability and choice of any given practice depends on management objectives and the age, form, structure, and condition of the stand. The major distinction between acceptable silvicultural practices for mixed species stands and for pure lodgepole pine stands is the opportunity in mixed species stands for species discrimination in stocking control and partial harvest cuttings.

Stocking control, with species discrimination, is applicable in immature mixed species stands (fig. 86).

Figure 82.—Even-aged western larch, lodgepole pine stand. A common stand situation in northwest Montana.

Figure 83.—Mixed, even-aged stands of lodgepole pine and Engelmann spruce occur both east and west of the Continental Divide.

Figure 84.—Mixed overstory of lodgepole pine, spruce, and subalpine fir with a mixed understory of climax species.

Figure 85.—Overstory of lodgepole pine and western larch with understory of shade-tolerant species. The western larch is severely infected with dwarf mistletoe.

Figure 86.—Lodgepole pine was discriminated against in this thinned immature western larch-lodgepole pine stand. The vigorous, well-stocked western larch crop trees are capable of excellent yield.

In older mixed species stands, we can discriminate against lodgepole pine by cutting only the larger trees. This is a valid practice in regulated forests only if the residual stand is of sufficient vigor and stocking to maintain stand growth near the capability level of the site or if the objective is a shelterwood or seed tree cut (fig. 87) in preparation for stand regeneration.

Partial cutting of larger lodgepole pine from a stand is sometimes justified in the short term—in both pure and mixed species lodgepole pine stands threatened with outbreaks—in order to deny the beetle the trees needed for population buildup. It thus can help provide additional time for other measures, more appropriate for large-scale application, to be applied.

Partial cutting has been demonstrated to reduce subsequent beetle infestation levels in numerous tests of susceptible lodgepole pine stands (Cole and others 1983; Cole and McGregor, in press; Hamel 1978; Cahill 1978; Cole and Cahill 1976). However, because the intent of most of these tests was to determine if partial cutting could be used to manage beetle populations (infestation levels), its qualifications as a practice for maintaining stand productivity were not emphasized. Amman (1976) concluded that partial cutting is sometimes an option where timber values are primary but applies only where (1) a small proportion of the lodgepole pine have large diameters and thick phloem conducive to beetle buildup and (2) residual trees would be numerically adequate and vigorous enough to maintain stand productivity.

Usually only stands having a sizable and healthy basal area component of other species can provide a residual stand capable of attaining the yield capability of the site. Discriminating against the beetle-preferred lodgepole pine in such stands can be silviculturally acceptable, but the volume involved may not be economical to remove. Conversely, removal of sufficient additional volume of other species may overcut the stand (fig. 88). The volume of beetle-preferred trees may not be enough to pay for the road system. Thus, maintaining adequate growing stock must be considered important enough to subsidize development costs where only a small proportion of the lodgepole pine volume is susceptible in any one infestation cycle (D. M. Cole 1978).

When complete or partial removal of the overstory is used, future productivity is likely to be further impaired by logging damage, dwarf mistletoe (*Arceuthobium americanum* Nutt. ex Engel.) infection, and windthrow (Hatch 1967; Alexander 1972, 1975). The yield-reducing effect of dwarf mistletoe infection, in itself a serious management problem, becomes even more serious in multistoried stands where lodgepole pine understories are infected. It is extremely doubtful if yield capability of the site can be attained if such understories are featured in management through partially cutting the overstory, unless costly mistletoe control programs are carried out. Thus the dwarf mistletoe factor needs careful consideration when partial cuts are contemplated for beetle control purposes (D. M. Cole 1978). If partial cutting is otherwise defensible in dwarf mistletoe infected stands, residual infected trees should be removed before lodgepole pine regeneration is 10 years old or taller than 3 ft (0.9 m) (Hawksworth 1975).

Figure 87.—Lodgepole pine was discriminated against in harvesting this mixed species situation, leaving western larch seed trees to regenerate the stand.

Figure 88.—In discriminating against beetle-susceptible lodgepole pine, removal of sufficient additional volume, including other species, to make the sale economically viable, may result in overcutting the stand and have adverse effects on other resource values.

The risk of windfall is increased by such factors as poor drainage, shallow soils, and defective roots and boles. Stands exposed to special topographic features, such as gaps and saddles at higher elevations, have higher windfall risk, and the risk increases in all stands regardless of exposure when the stand is opened up by intermediate cutting or partial cutting of the overstory (Alexander 1975). Susceptibility of residual trees to windthrow is generally greater in stands cut from above than in those cut from below. Root system development varies with soil and stand conditions. On deep, well-drained soils, trees have a better root system than on shallow or poorly drained soils. With the same conditions, the more dense the stand, the less windfirm are individual stems because trees that develop together in dense stands over long periods of time support each other and do not have roots and boles able to withstand exposure to wind if opened up drastically. The risk of windthrow is also greater on some exposures than others. Further detail on procedures for properly identifying and dealing with windfall risk in partial cutting of lodgepole pine can be found in the guidelines of Alexander (1964, 1967).

Other Practices for Commercial Forests

Another strategy to reduce losses to the mountain pine beetle is the use of behavior-modifying chemicals called Semiochemicals (Borden and others 1983a). These are combinations of pheromones produced by the beetle and terpenes of the host tree. Pheromones are chemical messengers used by insects for communication. They trigger behavioral responses which result in aggregation. Behavior-modifying chemicals can be used effectively to (1) contain small infestations, preventing them from spreading into adjacent green stands (Borden and others 1983b; Conn and others 1983); (2) bait and trap small developing outbreaks (Borden and others 1983a; Conn and others 1983); and (3) to manipulate or trap small populations after logging (Borden and others 1983b). Also, Semiochemicals placed in release devices (funnel traps) provide a tool for monitoring infestation levels. In forest pest management programs, pheromone trapping systems also provide foresters with data necessary for making procedural changes in logging and log storage and handling.

Trees baited with Semiochemicals can also be used in conjunction with Sevimol-4 (a pesticide) as lethal trap trees, in combination with felling and burning of infested trees in isolated developing outbreaks, or in drainages where clearcutting has exceeded the amount allowed by watershed and regenerated-area guidelines. Baiting-trapping can also be used in conjunction with large-scale harvesting to reduce beetle populations. In areas where outbreaks are just developing, the stands designated for harvest can be baited on a 55-yd (50-m) grid (Borden and others 1983c; S. Lindgren 1983), then clearcut following beetle attack of the baited-trap trees. It would be necessary to ensure removal and milling of these trees before beetle flight the following year.

Stands designated for partial cutting can be baited on a 27-yd (25-m) grid along roads, then on a 55-yd (50-m) grid surrounding the stands or infestation centers (Borden and others 1983c; S. Lindgren 1983). This strategy is recommended for small infestation centers (groups of 3 to 20 trees). For medium-size infestations of 5 to 50 acres (2 to 20 ha), where the goal is containment, it is recommended that lures be placed on one tree every 55 yd (50 m) on a grid basis, so that flying beetles will pass within 27 yd (25 m) of a baited tree (S. Lindgren 1983). A cut-tree zone should also be created around the baited infestation center. This strategy would be effective for smaller stands or small group selection cuts.

For infestations larger than 50 acres (20 ha), it is of no concern if beetles fly about within the infested area; therefore, we recommend that two bait lines, 55 yd

(50 m) apart with a tree baited every 55 yd (50 m), be placed in a band within the margin of the infestation to intercept flying beetles attempting to leave the infestation center. Baited trees should be at least 27 yd (25 m) inside any exposed margin (S. Lindgren 1983). This strategy is applicable where drainages are coming under management and the objective is to obtain a mosaic of age and size classes in even-aged lodgepole pine stands. Such trappings can contain beetle infestations, reduce damage, and buy time for other preventative measures. It is also useful where one desires to maintain hiding/thermal cover or to protect riparian and visual values from the effects of the mountain pine beetle.

PRACTICES AND CONSIDERATIONS FOR NONCOMMERCIAL FORESTS

Mark D. McGregor
Cooperative Forestry and Pest Management
Northern Region
Missoula, MT

Dennis M. Cole
Intermountain Forest and Range
Experiment Station
Forestry Sciences Laboratory
Bozeman, MT

Fragile Higher Elevation Ecosystems

Mountain pine beetle outbreaks usually begin and develop to epidemic levels in susceptible lodgepole pine stands at lower elevations and eventually progress to higher elevations after depleting the lower elevation lodgepole pine. At higher elevations, whitebark pine (*Pinus albicaulis*) is also attacked (fig. 89).

Extensive stands of whitebark pine occur above 6,000 ft (1 830 m) elevation in some forests. Habitat types are *A. lasiocarpa-P. albicaulis/V. scoparium*, *A. lasiocarpa/Luzula hitchcockii*, and *P. albicaulis-A. lasiocarpa*. Stands in these habitat types are often economically inaccessible. Soils are shallow, and timber production is usually low (20 ft^3/acre [1.4 m^3/ha] per year), although some large trees up to 30 inches (76 cm) d.b.h. occur (Wilson 1979). Some stands are 450 to 500 years old. Although most stands in these habitat types are dominated by whitebark pine, there are extensive areas in the lower elevations of the *A. lasiocarpa-P. albicaulis/V. scoparium* habitat type where lodgepole pine is a significant stand component. (This was previously shown in the summary of the Gallatin National Forest habitat types.) In these transition zones, mountain pine beetle effects are serious.

On the Gallatin National Forest, the *A. lasiocarpa-P. albicaulis/V. scoparium* habitat type occupies 319,776 acres (129 411 ha)—about 19 percent of the Forest. This habitat type does not occur on the Flathead National Forest. The significance of this habitat type, of course, is that whitebark pine is also vulnerable to the mountain pine beetle. According to table 5, about one-third of the area represented by this habitat type on the Gallatin National Forest has over one-third of the stand basal area in lodgepole pine more than 8 inches (20 cm) d.b.h. These stands generally are in the lower elevation part of the habitat type, adjacent to habitat types of the *A. lasiocarpa* series, where lodgepole pine plays a major seral or dominant seral role. Because there is a high potential for beetle epidemics to build in adjacent lower elevation habitat types to eventually attack the larger lodgepole pine and then the whitebark pine in the *A. lasiocarpa-P. albicaulis/V. scoparium* habitat type, tree mortality and other resource losses can be very high. Silvicultural options are limited in this habitat type because current technology does not usually provide economic harvest or natural regeneration methods that ensure resource protection and stand regeneration following cutting in high-elevation whitebark pine stands. Planning for regeneration should be given high priority when cutting is contemplated in these fragile ecosystems.

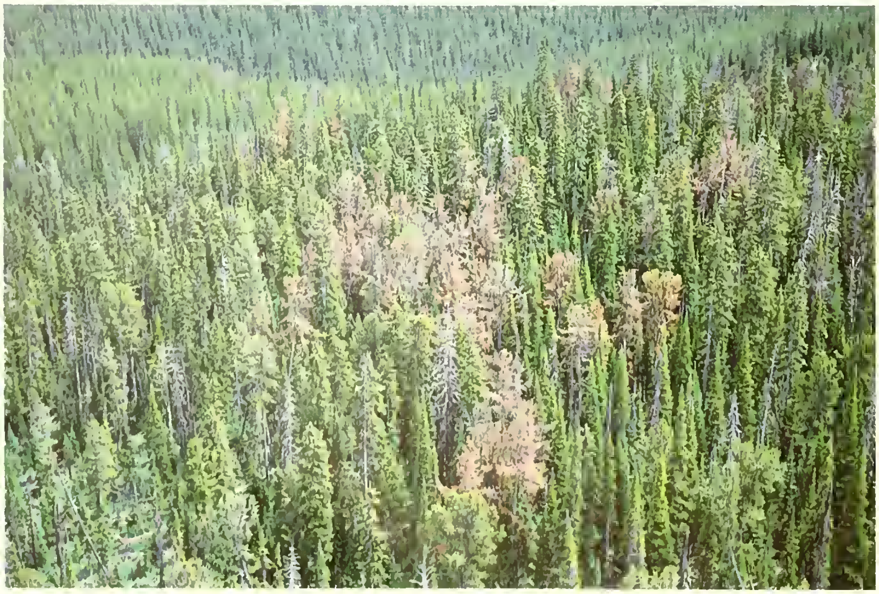


Figure 89.—Extensive stands of whitebark pine have become infested in fragile, high-elevation areas, often designated as critical wildlife habitat.

The first concern should be to hazard-rate and risk-rate stands at lower elevations and implement stand management practices there to prevent outbreaks from spreading into the whitebark pine zone. In conjunction with stand management, additional management practices are felling, piling, and burning infested trees in small-spot infestations and baiting and trapping to contain infestations (Borden and others 1983a, 1983b, 1983c; B. S. Lindgren 1983; S. Lindgren 1983).

Considerations for Parks, Wilderness, and Other Reserved Areas

In National Parks and ecological reserves or wilderness areas, high value is placed on maintaining a natural ecosystem. Mortality is generally considered in terms of visual resource impairment and increased costs to maintain convenience and safety for recreationists. Of the following management options for these areas, all except fire management are thought of as good housekeeping rather than silvicultural practices (D. M. Cole 1978).

Although seldom feasible, felling and burning infested trees in spot outbreaks can sometimes prevent or delay epidemics.

Fire has been largely responsible for maintaining lodgepole pine as a widespread forest type, so it must be considered in plans for parks, wilderness, and reserved areas.

Although wildland fires have been suppressed in parks and wildernesses for 50 to 60 years, the effects of fire exclusion in lodgepole pine ecosystems have not been as pronounced as in some other forest types—for example, ponderosa pine. The difference between how these two types respond to fire exclusion is explained largely by the fact that lodgepole pine has a natural fire cycle of 40 to 60 years while that of ponderosa pine is about 10 years. Succession and other effects of 50 to 60 years of fire suppression in lodgepole pine are therefore less than for the same period of fire exclusion in ponderosa pine (Mutch 1984). Nevertheless, mountain pine beetle epidemics, large fuel accumulations (fig. 90), and stand replacement fires (fig. 91) are a normal sequence for unmanaged lodgepole pine ecosystems. But naturally occur-

Figure 90.—Accumulations of dead wood resulting from earlier beetle epidemics in unmanaged stands.

Figure 91.—Heavy fuel loadings from mountain pine beetle epidemics and high burning conditions result in high-intensity, stand replacement fires.

ring stand replacement fires can be more destructive than managed or prescribed fires, and they can perpetuate future extremes in the mountain pine beetle/lodgepole pine/fire cycle (D. M. Cole 1978). This cycle can be moderated if a deliberate program of prescribed fire management is initiated (fig. 92).

There are two types of prescribed fires—those originating from unplanned ignitions and those from planned ignitions. Both types of prescribed fires have a place in management, and objectives should help in deciding which method to employ. Prescribed burning offers real silvicultural advantages over trying to manage naturally occurring fires in such high-hazard situations as beetle-infested areas (D. M. Cole 1978).

Visual considerations regarding fire management programs in wilderness need to be tested continually against the concept of wilderness—"areas to be affected primarily by the forces of nature." Thus, fires are not judged as good or bad in wilderness but simply viewed as one of several natural forces affecting wilderness ecosystems. Fires varying in intensity and size will affect foreground, middleground, and background views in significant but different ways. High-intensity fires often burn across main travel and viewing corridors in wilderness, leaving long-lasting scenes of scorched trees and blackened snags.

Ideally, a prescribed fire in wilderness should be used to create a dynamic ecosystem change similar to random natural fire—killing some trees but leaving others, removing undergrowth in places but also leaving unburned areas, exposing mineral soil, producing open-grown forests and dense stands of lodgepole pine, converting dead organic material to ash, recycling nutrients, restricting some plants and favoring others. Not only are fire-dependent communities well adapted to such change, but the diversity of plants and animals that follows fire contributes to ecosystem stability and landscape beauty. It should be noted that a similar prescribed fire program may be appropriate for back-country areas outside wilderness that are being managed primarily for wildlife and dispersed recreation (Habeck and Mutch 1975).

Reliable surveys and maps of stand age and size and fuels structure are necessary to develop a plan to allow some fires, once started, to burn under supervision to create a mosaic of regenerated stands within the extensive areas of large timber that have developed (fig. 93). Such mosaics are easier to accomplish with prescribed fire in wilderness areas than in the general forest zone.

In some wilderness areas, periodic crown fires play a vital role in natural development of lodgepole pine ecosystems, and their use should be considered when consistent with the need to protect human life, property, and resource values outside wilderness (Fischer and Clayton 1982).

Practices for Recreational, Home, and Administrative Sites

In recreation areas, home sites, and administrative sites, trapping and the use of protective sprays are preferred methods for protecting high-value trees. A protective spray that is effective and safe is Sevimol-4 (a pesticide) (Gibson and Bennett, in press). Sevimol-4 (1.0 percent) applied to the tree bole before beetle flight (fig. 9[illegible] will protect a tree for 2 years. Pine oil (a repellant), applied to the lower 10 to 15 ft (2.8 to 4.4 m) of the bole of green lodgepole pines has proven effective in repelling attacking mountain pine beetle (Nijholt and McMullen 1980; Nijholt and others 1981). However, additional field and pilot testing are planned before pine oil can be recommended for operational use. Baited traps hung outside campgrounds and administrative sites will attract beetles and help protect high-value sites during early developing or declining epidemics.

Managers of high-use recreation areas, such as campgrounds, should also consider planting trees of different species when planning such facilities or where lodgepole pine has been killed in existing sites. Hazard trees, both dead and those with root disease, should be removed for

Figure 92.—Prescribed fire can be beneficial to wildlife and reduce potential mountain pine beetle hazard.

safety and esthetic reasons. Trees baited in stands adjacent to campgrounds can be logged, chemically treated, or felled and burned. Pest management specialists should be consulted on locations and intervals of bait and trap placement and on proper use of pesticides, repellents, and attractants. Information on the availability of these chemicals can be obtained from Cooperative Forestry and Pest Management units at Forest Service Regional Offices.

Figure 93.—Supervised fires can create a mosaic of age classes, reducing area of susceptible high-hazard stands while benefiting other resources.

Figure 94.—Application of Sevimol-4 will protect high-value trees for up to 2 years.

INTEGRATING PEST MANAGEMENT FOR THE MOUNTAIN PINE BEETLE WITH MANAGEMENT FOR MULTIPLE RESOURCE GOALS

Mark D. McGregor
Cooperative Forestry and Pest Management
Northern Region
Missoula, MT

Dennis M. Cole
Intermountain Forest and Range
Experiment Station
Forestry Sciences Laboratory
Bozeman, MT

Beetle populations can be managed by a process in which known aspects of the mountain pine beetle/lodgepole pine system are evaluated and integrated with multiple resource management through a process called Integrated Pest Management (IPM). This provides the resource manager with information for limiting damage from mountain pine beetle to tolerable levels. To be most effective, IPM should include prevention, suppression, and postsuppression activities, developed in an ecological framework that addresses the needs of other forest resources.

An IPM system designed to reduce losses to the mountain pine beetle should emphasize prevention. Prevention is the best approach because techniques are more effective, economical, environmentally acceptable, and compatible with management for other forest resources. Nevertheless, the full array of available pest management responses must be considered in an orderly process to insure sufficient, cost-effective pest management prescriptions.

Such a process requires a systems approach to data assembly, analysis, and decisionmaking. Freeman's (1978) decisionmaking process as developed by Coster (1980) into a decision process and support system for developing integrated management strategies for the southern pine beetle (*Dendroctonus frontalis* Z.) is a good framework for developing an IPM system for the mountain pine beetle. We have adapted Coster's decision process into a suggested system for making integrated management decisions (fig. 95). Although this report is entitled "Integrating Management Strategies for the Mountain Pine Beetle with Multiple-Resource Management of Lodgepole Pine Forests," we do not presume to call the process presented here a complete IPM Program. Such a program can only be developed by forest managers, who must establish explicit management objectives and assign responsibilities for accomplishing them. Guidelines presented in this paper, however, support the suggested decisionmaking process and decision support system by providing information relative to Steps 3, 4, 5, 6, and 7 of figure 95, as discussed below.

EVALUATING THE PRESENT AND FUTURE PROBLEM

The Pest Management Team, in cooperation with the local Forester and Planner, can obtain data for Step No. 3. This will identify the problems: where, what species, current effects, relation or association with other pests, and prognosis for future damage. These data are obtained through (1) aerial and ground detection surveys, (2) biological evaluations and forest inventories, and (3) hazard rating surveys.

The detection of beetle infestations relies on observations of damage, which require observing and mapping individual trees or groups of trees with off-color foliage. It can be accomplished efficiently by the scheduled use of aircraft and trained observers at appropriate times of the year. Casual observations and reports by practicing foresters, woods workers, and other forest users provide a valuable source of information on unusual beetle activity. These reports are encouraged by continuing education and information programs by the Forest Service and other public agencies and, to some extent, by large forest landowners; however, timely and effective coverage of the extensive forest areas subject to beetle attack requires aerial surveillance on an annual basis.

The attractant pheromones provide another, more direct means of detecting significant increases in beetle numbers and potential damage (S. Lindgren 1983). Baited traps can be deployed on an annual basis to detect changes in mountain pine beetle populations.

The evaluation phase of monitoring by intensive surveys accomplishes three purposes: (1) it provides a quantitative basis for judging the need for direct suppression and for determining the type of actions that should be taken; (2) it provides the basis for evaluating the efficacy and benefits of the action(s) that are carried out; and (3) it provides a source of input data for models of stand dynamics and beetle populations, where such models are applicable. Annual biological evaluations are needed to keep the forest manager properly informed of situations warranting management action (Waters 1984).

The buildup and spread of beetle outbreaks often are evaluated solely in terms of the damage occurring. Specific information is needed by the resource manager on tree species, age and size classes affected, and on mortality rates in different stands. Forest inventory surveys supply data to the forest resource manager in terms of stand composition, stocking density, age-size structure, regeneration, and other relevant management planning data. They include data on tree mortality and defect, stand growth, changes in stand structure and composition, potential yield, and other dynamic variables of interest. Stage and Long (1976) describe the types of forest stand dynamics models that can make use of forest inventory data and the relevance of these to forest pest management. Estimates are also obtained from biological and stand surveys using the INDIDS model (Bousfield 1981) and the rate of loss model (Cole and McGregor 1983) previously described. Briefly, models are useful to the manager in determining:

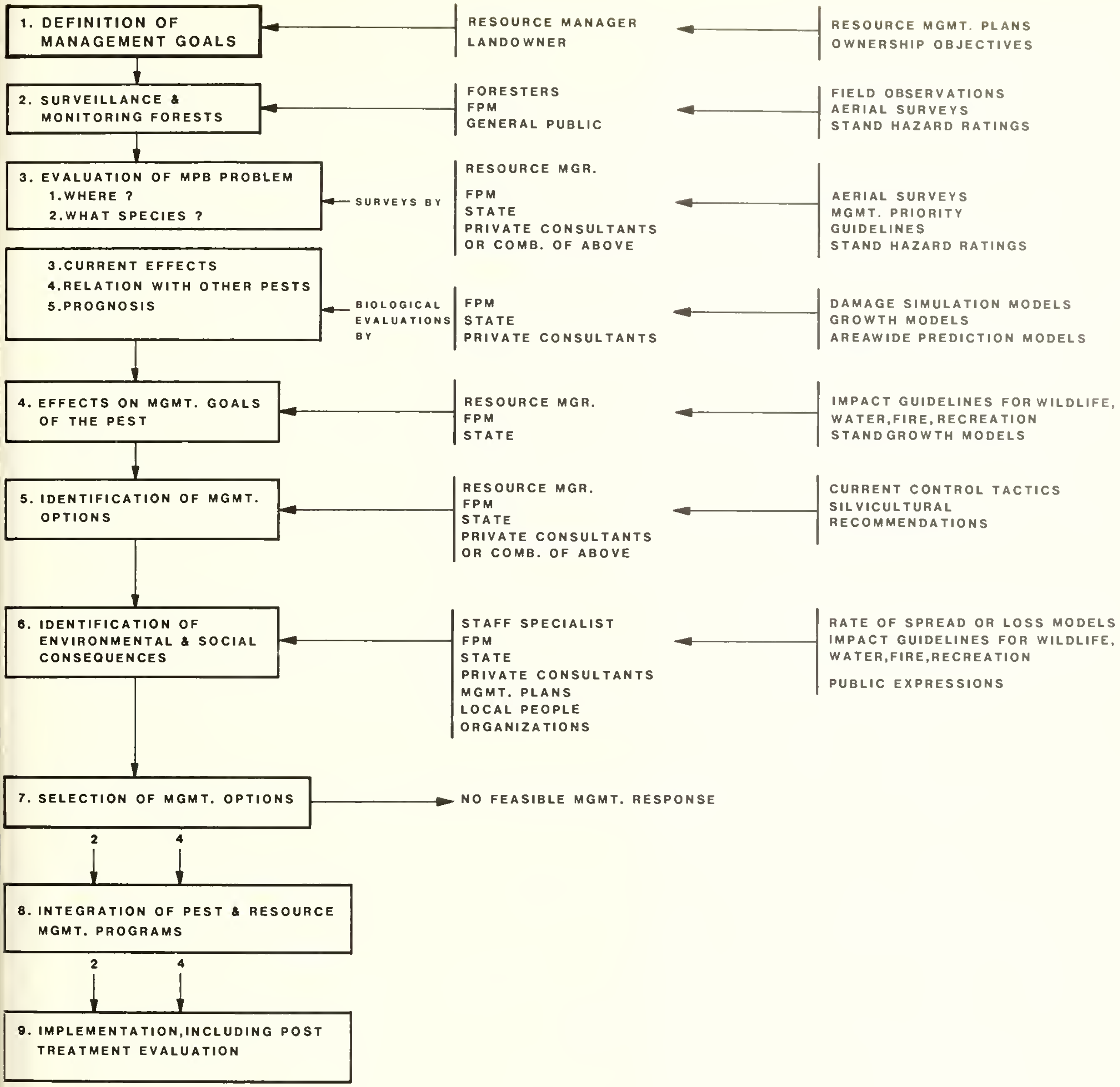


Figure 95.—Information and decision process for integrating pest management with management of multiple resources.

1. Expected losses for general information and planning purposes (Beckley 1983). Tree risk and stand/area hazard ratings serve several important functions in the management of the mountain pine beetle. Risk and hazard ratings are the sole means of forewarning the forest manager of potential beetle-caused losses and thus are essential to managers in taking preventative actions consistent with management objectives. They have a uniquely important place, therefore, in the management of pine bark beetles (Waters 1985).

2. Structure and composition of probable residual stands if outbreaks occur and are allowed to run their course. This helps managers to determine probable impacts on resource values such as big game cover and watershed and visual values.

3. Silvicultural alternatives. If characteristics of the postepidemic stand are predictable, it will be possible to narrow down the silvicultural options. For example, if the postepidemic stand is within acceptable stocking levels, the alternative of partial cutting is a viable option; but, if predicted losses are high, regeneration harvesting may be the only feasible alternative.

4. Priority for silvicultural treatments. Stands with the highest hazard and risk and potential resource inputs can be scheduled for treatment first.

EVALUATING MANAGEMENT GOALS AND OPTIONS

Both the resource management and the pest management specialist contribute information for determining the effect on management goals (Step 4, fig. 95). Available management options, their potential costs and benefits, and how they might affect outbreaks through prevention, or alteration of epidemics (Steps 5 and 6) should be evaluated by a pest/resource management team.

SELECTION AND INTEGRATION OF MANAGEMENT OPTIONS

After analyzing the management options and their cost effectiveness, a management option can be selected (Step 7, fig. 95). One might determine none of the options is cost effective or perhaps the environmental/social consequences of all actions are untenable. On the other hand, the decision might be to select one or more preventative or suppressive actions. For example, salvage logging, preventative spraying, stand thinning, and baiting-trapping may be selected to simultaneously manage existing infestations, recover some loss, and minimize future mortality. Programs developed to carry out the pest management actions should then be refined to give appropriate consideration to all important resources threatened by the mountain pine beetle or affected by management response to the pest (Step 8).

Cooperation between pest management specialists and resource managers is essential. Resource managers bear the responsibility for final decisions regarding management of multiple resources and must, therefore, spell out clearly the time, space, and economic limitations that these decisions place on silviculture and other pest management actions designed to minimize future losses to the mountain pine beetle.

IMPLEMENTATION

Prevention of resource losses is an idealized objective of forest pest management. Complete prevention of losses to the mountain pine beetle is, of course, not realistic. A realistic goal, implicit in the concept of integrated pest management, is to define a relatively long-term balance among resource values of lodgepole pine forests and to manage the forest and the mountain pine beetle to achieve and maintain the balance. The information and guidelines provided in the different sections of this report should prove valuable to forest planners and managers in proceeding with this complex integrating process.

REFERENCES

Abbey, Helen. An examination of the Reed-Frost theory of epidemics. Human Biology. 24: 201-233; 1952.

Alexander, R. R. Minimizing windfall around cuttings in spruce-fir forests. Forest Science. 10: 130-142; 1964.

Alexander, R. R. Windfall after clearcutting on Fool Creek-Fraser Experimental Forest, Colorado. Research Note RM-92. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station; 1967. 11 p.

Alexander, R. R. Partial cutting practices in old-growth lodgepole pine. Research Paper RM-92. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station; 1972. 16 p.

Alexander, R. R. Partial cutting in old-growth lodgepole pine. Research Paper RM-136. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station; 1975. 17 p.

Allen, E. O. A new perspective for elk habitat management. In: Proceedings, annual conference Western Association of Fish and Wildlife Agencies; Tucson, AZ. Tucson, AZ: [publisher unknown]; 1977: 195-205.

Amman, G. D. Mountain pine beetle emergence in relation to depth of lodgepole pine bark. Research Note INT-96. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1969. 8 p.

Amman, G. D. Mountain pine beetle brood production in relation to thickness of lodgepole pine phloem. Journal of Economic Entomology. 65: 138-140; 1972.

Amman, G. D. Population changes of the mountain pine beetle in relation to elevation. Environmental Entomology. 2: 541-547; 1973.

Amman, G. D. Insects affecting lodgepole pine productivity. In: Baumgartner, David M., ed. Management of lodgepole pine ecosystems; symposium proceedings; 1973 October 9-11; Pullman, WA. Pullman, WA: Washington State University, Cooperative Extension Service; 1975: 310-341.

Amman, G. D. Integrated control of the mountain pine beetle in lodgepole pine forests. In: XVI IUFRO World Congress, Proceedings Division II ; Oslo, Norway. 1976: 439-446.

Amman, G. D. The role of the mountain pine beetle in lodgepole pine ecosystems; impact on succession. In: Mattson, W. J., ed. Arthropods in forest ecosystems: proceedings in life sciences. New York: Springer-Verlag; 1977: 3-18.

Amman, G. D. The biology, ecology and causes of outbreaks of the mountain pine beetle in lodgepole pine forests. In: Berryman, Alan A.; Amman, Gene D.; Stark, Ronald W., tech. eds. Theory and practice of mountain pine beetle management in lodgepole pine forests: symposium proceedings; 1978 April 25-27; Pullman, WA. Moscow, ID: University of Idaho, Forest, Wildlife and Range Experiment Station; 1978: 39-53.

Amman, G. D. A test of lodgepole pine hazard rating methods for mountain pine beetle infestation in southeastern Idaho. In: Safranyik, Les, ed. The role of host-pest interaction in the population dynamics of forest insects: proceedings of the IUFRO Working Parties S2-07-05, 06 symposium; 1983 September 4-7; Banff, Alberta, Canada; [in press].

Amman, G. D.; Baker, B. H. Mountain pine beetle influence on lodgepole pine stand structure. Journal of Forestry. 7: 204-209; 1972.

Amman, G. D.; Baker, B. H.; Stipe, L. E. Lodgepole pine losses to mountain pine beetle related to elevation. Research Note INT-171. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1973. 8 p.

Amman, G. D.; Cole, W. E. Mountain pine beetle dynamics in lodgepole pine forests. Part II: population dynamics. General Technical Report INT-145. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1983. 59 p.

Amman, G. D.; McGregor, M. D.; Cahill, D. B.; Klein, W. H. Guidelines for reducing losses of lodgepole pine to the mountain pine beetle in unmanaged stands in the Rocky Mountains. General Technical Report INT-36. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1977. 19 p.

Bacon, W. R.; Twombly, A. D. National forest landscape management. In: Agriculture Handbook 559. Washington, DC: U.S. Department of Agriculture, Forest Service; 1977: vol. 2, chapter 5.

Basile, J. V.; Jensen, C. E. Grazing potential on lodgepole pine clearcuts in Montana. Research Paper INT-98. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1971. 11 p.

Beckley, P. [Personal communication]. 1983. Author located at: Tally Lake Ranger District, Flathead National Forest, Whitefish, MT.

Berryman, A. A. A synoptic model of the lodgepole pine/mountain pine beetle interaction and its potential application in forest management. In: Berryman, Alan A.; Amman, Gene D.; Stark, Ronald W., tech. eds. Theory and practice of mountain pine beetle management in lodgepole pine forests: symposium proceedings; 1978 April 25-27; Pullman, WA. Moscow, ID: University of Idaho, Forest, Wildlife and Range Experiment Station; 1978: 98-105.

Black, H.; Sherzinger, R.; Thomas, J. W. Relationships of Rocky Mountain elk and Rocky Mountain mule deer habitat to timber management in the Blue Mountains of Oregon and Washington. In: Hieb, Susan R., ed. Proceedings of the elk-logging-roads symposium; 1975 December 16-17; Moscow, ID. Moscow, ID: University of Idaho; 1976: 11-31.

Blanchard, B. M. Grizzly-habitat relationship in Yellowstone area. In: Meslow, E. Charles, ed. Bears—their biology and management: proceedings 5th international conference on bear research and management; 1980 February 10-13; Madison, WI. Madison, WI: International Association for Bear Research and Management; 1980: 119-123.

Borden, J. H.; Conn, J. E.; Friskie, L. M.; Scott, B. E.; Chong, L. J. Semiochemicals for the mountain pine beetle, *Dendroctonus ponderosae* (Coleoptera: Scolytidae), in British Columbia: baited-tree studies. Canadian Journal of Forest Research. 13: 325-333; 1983

Borden, J. H.; Chong, L. J.; Fuchs, M. C. Application of Semiochemicals in post-logging manipulation of the mountain pine beetle, *Dendroctonus ponderosae* (Coleoptera: Scolytidae). Journal of Economic Entomology. 76(6): 1428-1432; 1983

Borden, J. H.; Chong, L. J.; Pratt, K. E. G.; Gray, D. R. The application of behavior-modifying chemicals to contain infestation of the mountain pine beetle, *Dendroctonus ponderosae*. Forestry Chronicle; 1983 October: 235-239.

Bousfield, Wayne E. R-1 forest insect and disease damage survey system. Report 70-2 (rev.). Missoula, MT: U.S. Department of Agriculture, Forest Service, Northern Region; 1981. 12 p.

Cabrera, Homero. Phloem structure and development in lodgepole pine. In: Berryman, Alan A.; Amman, Gene D.; Stark, Ronald W., tech. eds. Theory and practice of mountain pine beetle management in lodgepole pine forests: symposium proceedings; 1978 April 25-27; Pullman, WA. Moscow, ID: University of Idaho, Forest, Wildlife and Range Experiment Station; 1978: 54-63.

Cahill, D. B. Cutting strategies as a control measure of the mountain pine beetle in lodgepole pine in Colorado. In: Berryman, Alan A.; Amman, Gene D.; Stark, Ronald W., tech. eds. Theory and practice of mountain pine beetle management in lodgepole pine forests: symposium proceedings; 1978 April 25-27; Pullman, WA. Moscow, ID: University of Idaho, Forest, Wildlife and Range Experiment Station; 1978: 188-191.

Carter, S. William, Jr. Potential impacts of mountain pine beetle and their mitigation in lodgepole pine stands. In: Berryman, Alan A.; Amman, Gene D.; Stark, Ronald W., tech. eds. Theory and practice of mountain pine beetle management in lodgepole pine forests: symposium proceedings; 1978 April 25-27; Pullman, WA. Moscow, ID: University of Idaho, Forest, Wildlife and Range Experiment Station; 1978: 54-63.

Cole, D. M. Estimating phloem thickness in lodgepole pine. Research Paper INT-148. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1973. 10 p.

Cole, D. M. Culture of immature lodgepole pine stands for timber objectives. In: Baumgartner, David A., ed. Management of lodgepole pine ecosystems: symposium proceedings; 1973 October 9-11; Pullman, WA. Pullman, WA: Washington State University, Cooperative Extension Service; 1975: 536-555.

Cole, D. M. Feasibility of silviculture practices for reducing losses to the mountain pine beetle in lodgepole pine forests. In: Berryman, Alan A.; Amman, Gene D.; Stark, Ronald W., tech. eds. Theory and practice of mountain pine beetle management in lodgepole pine forests: symposium proceedings; 1978 April 25-27; Pullman, WA. Moscow, ID: University of Idaho, Forest, Wildlife and Range Experiment Station; 1978: 149-157.

Cole, W. E.; Amman, G. D. Mountain pine beetle infestations in relation to lodgepole pine diameters. Research Note INT-95. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1969. 7 p.

Cole, W. E.; Amman, G. D. Mountain pine beetle dynamics in lodgepole pine forests. Part I: course of an infestation. General Technical Report INT-89. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1980. 56 p.

Cole, W. E.; Amman, G. D.; Jensen, C. E. Mathematical models for the mountain pine beetle-lodgepole pine interaction. Environmental Entomology. 5: 11-19; 1976.

Cole, W. E.; Cahill, D. B. Cutting strategies can reduce probabilities of mountain pine beetle epidemics in lodgepole pine. Journal of Forestry. 74: 294-297; 1976.

Cole, W. E.; Cahill, Donn B.; Lessard, Gene. Harvesting strategies for management of mountain pine beetle infestations in lodgepole pine: preliminary evaluation, East Long Creek Demonstration area, Shoshone National Forest, Wyoming. Research Note INT-333. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1983. 11 p.

Cole, W. E.; McGregor, M. D. Estimating the rate and amount of tree loss from mountain pine beetle infestations. Research Paper INT-318. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1983. 22 p.

Cole, W. E.; McGregor, M. D. Reducing/preventing mountain pine beetle outbreaks in lodgepole pine stands by selection cutting. In: Safranyik, Les and Alan Berryman, ed. The role of host-pest interaction in the population dynamics of forest insects: proceedings of the IUFRO Working Parties S2-07-05,06 symposium; 1983 September 4-7; Banff, Alberta, Canada; [in press].

Conn, J. E.; Borden, J. H.; Scott, B. E.; Friskie, L. M. Semiochemicals for the mountain pine beetle *Dendroctonus ponderosae* (Coleoptera: Scolytidae) in British Columbia: field trapping studies. Canadian Journal of Forest Research. 13: 320-324; 1983.

Coster, J. E. Developing integrated management strategies. In: Thatcher, R. C.; Searcy, J. L.; Coster, J. E.; Hertel, G. D. The southern pine beetle. Technical Bulletin 1631. Washington, DC: U.S. Department of Agriculture, Forest Service, Expanded Southern Pine Beetle Research and Application Program; 1980: 195-203.

Daubenmire, R. Vegetation: identification of typal communities. Science. 151: 291-298; 1966.

Daubenmire, R.; Daubenmire, J. B. Forest vegetation of eastern Washington and northern Idaho. Technical Bulletin 60. Pullman, WA: Washington Agricultural Experiment Station; 1968. 104 p.

Despain, D. G. Vegetation of the Bighorn Mountains of Wyoming in relation to substrate and climate. Ecological Monographs. 43: 329-355; 1973.

Edgerton, P. J. Big game use and habitat changes in a recently logged mixed conifer forest in northeastern

Oregon. In: Proceedings, Western Association of State Game and Fish Commissioners. 52: 239-246; 1972.
Edminster, C. B. RMYLD: computation of yield tables for even-aged and two-storied stands. Research Paper RM-199. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station; 1978. 26 p.
Fischer, W. C.; Clayton, B. D. Fire ecology of Montana forest habitat types east of the Continental Divide. General Technical Report INT-141. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1982. 83 p.
Franklin, J. E.; Dyrness, C. T. Natural vegetation of Oregon and Washington. General Technical Report PNW-8. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1973. 417 p.
Freeman, W. L., Jr. Control planning and decision making. In: Scharf, R. F.; Parmeter, J. R., Jr., tech. eds. Proceedings of a symposium of dwarf mistletoe control through forest management; Berkeley, CA. General Technical Report PSW-31. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station; 1978: 31-35.
Gibson, K.; Bennett, D. Effectiveness of Carbaryl in preventing attacks on lodgepole pine by the mountain pine beetle. Journal of Forestry. [In press].
Gilbert, S.; Shite, B.; Kong, R.; Dennee, B.; Dahlgren, G.; Gay, R. Decisions (agreements/disagreements): Gallatin National Forest plan. In: Meeting report: the proposed Northern Region plan. Missoula, MT: U.S. Department of Agriculture, Forest Service, Northern Region; 1980: 86-94.
Habeck, J. R.; Mutch, R. W. Forests and forestry. Yearbook of Science and Technology. New York: McGraw-Hill; 1975.
Hamel, D. R. Results of harvesting strategies for management of mountain pine beetle infestation in lodgepole pine on the Gallatin National Forest, Montana. In: Berryman, Alan A.; Amman, Gene D.; Stark, Ronald W., tech. eds. Theory and practice of mountain pine beetle management in lodgepole pine forests: symposium proceedings; 1978 April 25-27; Pullman, WA. Moscow, ID: University of Idaho, Forest, Wildlife and Range Experiment Station; 1978: 192-196.
Harper, J. A. Relations of elk to reforestation in the Pacific Northwest. In: Black, Hugh, ed. Wildlife and reforestation in the Pacific Northwest. Corvallis, OR: Oregon State University; 1969: 67-71.
Harper, J. A. Ecology of Roosevelt elk. Portland, OR: Oregon State Game Commission; 1971. 44 p.
Hatch, C. R. Effect of partial cutting in over-mature lodgepole pine. Research Note INT-66. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1967. 7 p.
Hawksworth, F. G. Dwarf mistletoe and its role in lodgepole pine ecosystems. In: Baumgartner, David A., ed. Management of lodgepole pine ecosystems: symposium proceedings; 1973 October 9-11; Pullman, WA. Pullman, WA: Washington State University, Cooperative Extension Service; 1975: 342-358.
Hawksworth, Frank G.; Hinds, T. E.; Johnson, D. W.; Landis, T. D. Silvicultural control of dwarf mistletoe in young lodgepole pine stands. Technical Report 122-10. Lakewood, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Region, Forest Insect and Disease Management; 1977. 12 p.
Hedden, Roy L. Hazard-rating system development and validation: an overview. In: Hedden, Roy L.; Barras, Stanley J.; Coster, Jack E. Hazard-rating systems in forest insect pest management: symposium proceedings; 1980 July 31-August 1; Athens, GA. General Technical Report WO-27. Washington, DC: U.S. Department of Agriculture, Forest Service; 1981: 9-12.
Hein, D. Management of lodgepole pine for birds. In: DeGraff [DeGraaf], Richard M., tech. coord. Workshop proceedings: management of western forests and grasslands for nongame birds; 1980 February 11-14; Salt Lake City, UT. General Technical Report INT-86. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1980: 238-247.
Hershey, T. J.; Leege, T. A. Influences of logging on elk on summer range in north-central Idaho. In: Hieb, Susan R., ed. Proceedings of the elk-logging-roads symposium; 1975 December 16-17; Moscow, ID. Moscow, ID: University of Idaho; 1976: 73-80.
Kirsh, J. B. Little Belt elk food habits and range use investigations. Job Completion Report W-9 8-R-2. Helena, MT: Montana Department of Fish, Wildlife, and Parks, Montana Fish and Game Department; 1962. 44 p. Multilith.
Leaf, Charles F. Watershed management in the Rocky Mountain subalpine zone: the status of our knowledge. Research Paper RM-137. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station; 1975. 31 p.
Lemos, J. C.; Hines, W. W. Ecological study of Roosevelt elk. Job Progress Report W-70-R-4. Salem, OR: Oregon Wildlife Commission; 1974. 40 p.
Lindgren, B. S. A multiple funnel trap for scolytid beetles (Coleoptera). Canadian Entomologist. 115: 299-302; 1983.
Lindgren, S. Mountain pine beetle technical bulletin. Vancouver, BC: PMG/Stratford Projects Ltd.; 1983. 4 p.
Lonner, T. N.; Cada, J. D. Some effects of forest management on elk hunting opportunity. Paper presented at: Western States Elk Workshop, Arizona Fish and Game Department, Flagstaff, AZ; 1982.
Lorio, P. L., Jr. Developing stand risk classes for the southern pine beetle. Research Paper SO-114. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station; 1978. 16 p.
Lotan, J. E.; Perry, D. A. Ecology and regeneration of lodgepole pine. Agriculture Handbook 606. Washington, DC: U.S. Department of Agriculture, Forest Service; 1983. 51 p.
Lyon, L. J. Elk use as related to characteristics of clearcuts in western Montana. In: Hieb, Susan R., ed. Proceedings of the elk-logging-roads symposium; 1975 December 16-17; Moscow, ID. Moscow, ID: University of Idaho; 1976: 69-72.

Lyon, L. J. Habitat effectiveness for elk as influenced by roads and cover. Journal of Forestry. 77: 658-659; 1979.

Lyon, L. J.; Jensen, C. E. Management implications of elk and deer use of clearcuts in Montana. Journal of Wildlife Management. 44(2): 352-362; 1980.

Lyon, L. J.; O'Neill, T. A. Tests of elk guidelines: 1980 validation. Missoula, MT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1981. 4 p.

Mahoney, R. B. Lodgepole pine/mountain pine beetle risk classification methods and their application. In: Berryman, Alan A.; Amman, Gene D.; Stark, Ronald W., tech. eds. Theory and practice of mountain pine beetle management in lodgepole pine forests: symposium proceedings; 1978 April 25-27; Pullman, WA. Moscow, ID: University of Idaho, Forest, Wildlife and Range Experiment Station; 1978: 106-113.

McCambridge, W. F. Influence of low temperatures on attack, oviposition and larval development of mountain pine beetle, *Dendroctonus ponderosae* (Coleoptera: Scolytidae). Canadian Entomologist. 106: 979-984; 1974.

McGregor, M. D. Management of mountain pine beetle in lodgepole pine stands in the Rocky Mountain area. In: Berryman, Alan A.; Amman, Gene D.; Stark, Ronald W., tech. eds. Theory and practice of mountain pine beetle management in lodgepole pine forests: symposium proceedings; 1978 April 25-27; Pullman, WA. Moscow, ID: University of Idaho, Forest, Wildlife and Range Experiment Station; 1978: 129-139.

McGregor, M. D.; Amman, G. D.; Cole, W. E. Hazard-rating lodgepole pine for susceptibility to mountain pine beetle infestation. In: Hedden, Roy L.; Barras, Stanley J.; Coster, Jack E. Hazard-rating systems in forest insect pest management: symposium proceedings; 1980 July 31-August 1; Athens, GA. General Technical Report WO-27. Washington, DC: U.S. Department of Agriculture, Forest Service; 1981: 99-104.

McGregor, M. D.; Amman, G. D.; Schmitz, R. F.; Oakes, R. D. Silvicultural practices to reduce losses of lodgepole pine to mountain pine beetles. Canadian Journal of Forest Research. [In press].

Mealey, S. P.; Jonkel, C. J.; Demarchi, R. Habitat criteria for grizzly bear management. In: Proceedings XIIIth International Congress of Game Biologists. Washington, DC: Wildlife Management Institute; 1977; 12: 276-289.

Mitchell, R. G.; Waring, R. H.; Pitman, G. B. Thinning lodgepole pine increases the vigor and resistance to mountain pine beetle. Forest Science. 29(1): 204-211; 1983.

Montana Cooperative Elk-Logging Study. Progress report for the period, January 1-December 31, 1977. Annual Progress Report R-1. Missoula, MT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; Montana Department of Fish and Game; Bureau of Land Management; University of Montana, School of Forestry; 1978. 20 p.

Mutch, R. [Personal communication]. 1984. Author located at: Northern Region, Forest Service, U.S. Department of Agriculture, Missoula, MT.

Nijholt, W. W.; McMullen, L. H. Pine oil prevents mountain pine beetle attack in living lodgepole pine trees. Canadian Bi-Monthly Report. 36(2); 1980.

Nijholt, W. W.; McMullen, L. H.; Safranyik, L. Pine oil protects living trees from attack by three bark beetle species, *Dendroctonus* spp. [Coleoptera: Scolytidae]. Canadian Entomologist. 113: 337-340; 1981.

Peek, J. M.; Scott, M. D.; Pierce, D. J.; Erwin, L. L. Role of cover in habitat management for big game in the northwestern United States. In: Transactions of the North American Wildlife and Natural Resource Conference. 47: 363-373; 1983.

Pengelly, W. L. Clearcutting: detrimental aspects for wildlife resources. Journal of Soil and Water Conservation. 27(6): 225-258; 1972.

Perry, C.; Overly, R. Impact of roads on big game distribution in portions of the Blue Mountains of Washington, 1972-1973. Bulletin 11. Olympia, WA: Washington Game Department, Applied Research Section; 1977. 39 p.

Pfister, R. D.; Daubenmire, R. Ecology of lodgepole pine (*Pinus contorta* Dougl.). In: Baumgartner, David M., ed. Management of lodgepole pine ecosystems: symposium proceedings; 1973 October 9-11; Pullman, WA. Pullman, WA: Washington State University, Cooperative Extension Service; 1975: 27-46.

Pfister, R. D.; Kovalchik, B. L.; Arno, S. F.; Presby, R. C. Forest habitat types of Montana. General Technical Report INT-34. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1977. 174 p.

Rasmussen, L. A. Flight and attack behavior of mountain pine beetles in lodgepole pine of northern Utah and southern Idaho. Research Note INT-180. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1974. 7 p.

Reynolds, H. G. Use of natural openings in a ponderosa pine forest of Arizona by deer, elk, and cattle. Research Note RM-78. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station; 1962. 4 p.

Reynolds, H. G. Use of natural openings in spruce-fir forests of Arizona by elk, deer, and cattle. Research Note RM-66. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station; 1966. 4 p.

Ritchie, B. W. Ecology of moose in Fremont County, Idaho. Wildlife Bulletin No. 7. Boise, ID: Idaho Department of Fish and Game; 1978. 33 p.

Roe, A. L.; Amman, G. D. The mountain pine beetle in lodgepole pine forests. Research Paper INT-71. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1970. 23 p.

Rost, G. R.; Bailey, J. A. Distribution of mule deer and elk in relation to roads. Journal of Wildlife Management. 43: 634-641; 1979.

Rost, Maynard T. Comments on the mountain pine beetle/lodgepole pine symposium. In: Berryman, Alan A.; Amman, Gene D.; Stark, Ronald W., tech. eds. Theory and practice of mountain pine beetle management in lodgepole pine forests: symposium proceedings; 1978 April 25-27; Pullman, WA. Moscow, ID: University of Idaho, Forest, Wildlife and Range Experiment Station; 1978: 205-207.

Ruediger, W.; Mealey, S. Coordination guidelines for timber harvesting in grizzly bear habitat in northwestern Montana. Unpublished paper on file at: U.S. Department of Agriculture, Forest Service, Kootenai National Forest, Libby, MT; 1978. 44 p.

Safranyik, L. Effects of climate and weather on mountain pine beetle populations. In: Berryman, Alan A.; Amman, Gene D.; Stark, Ronald W., tech. eds. Theory and practice of mountain pine beetle management in lodgepole pine forests: symposium proceedings; 1978 April 25-27; Pullman, WA. Moscow, ID: University of Idaho, Forest, Wildlife and Range Experiment Station; 1978: 77-86.

Safranyik, L. Alternative solutions—preventive management and direct control. In: Shrimpton, D. M., ed. Proceedings of the joint Canada/USA workshop on mountain pine beetle related problems in western North America; 1981 November 3-4; Fairmont Hot Springs, BC. Information Report BC-X-230. Victoria, BC: Environment Canada, Canadian Forestry Service, Pacific Research Centre; 1982: 29-32.

Safranyik, L.; Shrimpton, D. M.; Whitney, H. S. Management of lodgepole pine to reduce losses from the mountain pine beetle. Technical Report 1. Victoria, BC: Canadian Department of the Environment, Forestry Service, Pacific Forest Research Centre; 1974. 24 p.

Safranyik, L.; Shrimpton, D. M.; Whitney, H. S. An interpretation of the interaction between lodgepole pine, the mountain pine beetle and its association with bluestain fungi in western Canada. In: Baumgartner, David M., ed. Management of lodgepole pine ecosystems: symposium proceedings; 1973 October 9-11; Pullman, WA. Pullman, WA: Washington State University, Cooperative Extension Service; 1975: 406-428.

Schenk, J. S.; Mahoney, R. L.; Moore, J. A. A model for hazard rating lodgepole pine stands for mortality by mountain pine beetle. Forest Ecology and Management. 3: 57-68; 1980.

Schladweiler, P. Moose ecology in southwestern Montana. Helena, MT: Montana Department of Fish, Wildlife, and Parks; 1973; Study No. 73.01 I0b, Final Report. 100 p.

Schmitz, R. [Personal communication]. 1984. Author located at: Intermountain Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture, Ogden, UT.

Servheen, C. Grizzly bear ecology and management in the Mission Mountains, Montana. Missoula, MT: University of Montana; 1981. 138 p. Ph.D. thesis.

Shrimpton, D. M. Age- and size-related response of lodgepole pine to inoculation with *Europhium clavigerum*. Canadian Journal of Botany. 51: 1155-1160; 1973.

Shrimpton, D. M.; Thomson, A. J. Use of physiological maturity to identify hazard of lodgepole pine stands from mountain pine beetles. In: Hedden, Roy L.; Barras, Stanley J.; Coster, Jack E. Hazard-rating systems in forest insect pest management: symposium proceedings; 1980 July 31-August 1; Athens, GA. General Technical Report WO-27. Washington, DC: U.S. Department of Agriculture, Forest Service; 1981: 149-153.

Singer, Robert J.; Maloney, Ralph C. Nonpoint source control guidance for silviculture. Washington, DC: U.S. Environmental Protection Agency, Office of Water Planning and Standards; 1977. 28 p.

Smithers, L. A. Thinning in lodgepole pine stands in Alberta. Technical Note 52. Ottawa, Canada: Canada Department of Northern Affairs and Natural Resources, Forest Research Division; 1957. 26 p.

Stage, A. R. Prognosis model for stand development. Research Paper INT-137. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1973. 32 p.

Stage, A. R.; Long, G. E. Forest stand dynamics as a basis for integrated management of forest pests. In: Kibbee, D. L., ed. The bases for integrated pest management: proceedings 16th International Union of Forestry Research Organizations, group 6; 1976 June; Oslo, Norway. Moscow, ID: University of Idaho; 1976: 19-28.

Tackle, D. A preliminary stand classification for lodgepole pine in the Intermountain Region. Journal of Forestry. 53: 566-569; 1955.

Thomas, Jack Ward, ed. Wildlife habitats in managed forests—the Blue Mountains of Oregon and Washington. Agriculture Handbook 553. Washington, DC: U.S. Department of Agriculture; 1979. 512 p.

Thomas, J. W.; Maser, C.; Rodiek, J. E. Edges—their interspersion, resulting diversity and its measurement. In: DeGraaf, R. M., tech. coord. Proceedings of the workshop on nongame bird habitat management in the coniferous forests of the Western United States; 1977 February 7-19; Portland, OR. General Technical Report PNW-64. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1978: 91-100.

Umatilla National Forest. Lane-Peet Study Area, mountain pine beetle outbreak. Pendleton, OR: U.S. Department of Agriculture, Forest Service, Umatilla National Forest; 1974; Interdisciplinary Team Report. 63 p.

U.S. Department of Agriculture, Forest Service. Forest statistics of the United States by State and region, 1970. Washington, DC; 1972. 96 p.

U.S. Department of Agriculture, Forest Service. Northern Region plan. Missoula, MT: U.S. Department of Agriculture, Forest Service, Northern Region; 1980.

U.S. Department of Agriculture, Forest Service. Canada/United States mountain pine beetle executive summary. Washington, DC; 1983. 16 p.

Van Sickle, G. A.; Wegwitz, E. Silvicultural control of dwarf mistletoe in young lodgepole pine stands in Alberta and British Columbia. Information Report BC-X-180. Victoria, BC: Canadian Forestry Service, Pacific Forest Research Centre; 1978. 10 p.

Wallmo, O. C. Response of deer to alternate-strip clear-cutting of lodgepole pine and spruce-fir timber in Colorado. Research Note RM-141. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station; 1969. 3 p.

Wallmo, O. C.; Schoen, J. Forest management for deer. In: Wallmo, O. C., ed. Mule and blacktailed deer of North America. Lincoln, NE: University of Nebraska Press; 1981: 434-438.

Ward, A. L. Elk behavior in relation to timber harvest operations and traffic on the Medicine Bow Range in south central Wyoming. In: Hieb, Susan R., ed. Proceedings of the elk-logging-roads symposium; 1975 December 16-17; Moscow, ID. Moscow, ID: University of Idaho; 1976: 32-43.

Waring, R. H.; Pitman, G. B. A simple model of host resistance to bark beetles. Research Note 65. Corvallis, OR: Oregon State University; 1980. 2 p.

Washburn, R. I.; Knopf, J. A. E. Mountain pine beetle conditions in the lodgepole pine stands of Forest Service, Region Four. 1959. Unpublished paper on file at: U.S. Department of Agriculture, Forest Service, Cooperative Forestry and Pest Management, Missoula, MT. 8 p.

Waters, W. E. Monitoring bark beetle populations and beetle-caused damage. In: Waters, W.E., R.W. Stark and D.L. Wood, eds. Integrated pest management in pine-bark beetle ecosystems. Wiley Interscience. New York: John Wiley and Sons, 1985: 141-175.

Wellner, C. A. Management problems resulting from mountain pine beetles in lodgepole pine forests. In: Berryman, Alan A.; Amman, Gene D.; Stark, Ronald W., tech. eds. Theory and practice of mountain pine beetle management in lodgepole pine forests: symposium proceedings; 1978 April 25-27; Pullman, WA. Moscow, ID: University of Idaho, Forest, Wildlife and Range Experiment Station; 1978: 9-15.

Wilson, G. Timber program review. Kalispell, MT: U.S. Department of Agriculture, Forest Service, Flathead National Forest; 1979. 3 p.

McGregor, Mark D.; Cole, Dennis M., editors. Integrating management strategies for the mountain pine beetle with multiple-resource management of lodgepole pine forests. General Technical Report INT-174. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1985. 68 p.

Provides guidelines for integrating practices for managing mountain pine beetle populations with silvicultural practices for enhancing multiple resource values of lodgepole pine forests. Summarizes published and unpublished technical information and recent research on the ecology of pest and host and presents visual and classification criteria for recognizing susceptibility status of lodgepole pine stands according to habitat types and successional roles of lodgepole pine. Reviews appropriate silvicultural systems and practices for commercial and noncommercial forest land designations and special administrative areas and outlines a systems approach for data acquisition, analysis, and management decisions in a process leading to integrated pest management of the mountain pine beetle.

KEYWORDS: mountain pine beetle, lodgepole pine, integrated pest management, ecological habitat types

OV INMENT PRINTING OFFICE: 1985—581-342 REGION NO. 8

The Intermountain Station, headquartered in Ogden, Utah, is one of eight regional experiment stations charged with providing scientific knowledge to help resource managers meet human needs and protect forest and range ecosystems.

The Intermountain Station includes the States of Montana, Idaho, Utah, Nevada, and western Wyoming. About 231 million acres, or 85 percent, of the land area in the Statlon territory are classified as forest and rangeland. These lands include grasslands, deserts, shrublands, alpine areas, and well-stocked forests. They supply fiber for forest industries; minerals for energy and industrial development; and water for domestic and industrial consumption. They also provide recreation opportunities for millions of visitors each year.

Field programs and research work units of the Statlon are maintained in:

Boise, Idaho

Bozeman, Montana (in cooperation with Montana State University)

Logan, Utah (in cooperation with Utah State University)

Missoula, Montana (in cooperation with the University of Montana)

Moscow, Idaho (in cooperatlon with the University of Idaho)

Provo, Utah (In cooperation with Brigham Young University)

Reno, Nevada (in cooperation with the University of Nevada)

United States
Department of
Agriculture

Forest Service

**Intermountain
Forest and Range
Experiment Station
Ogden, UT 84401**

General Technical
Report INT-175

December 1984

Managing Intermountain Rangelands — Research on the Benmore Experimental Range, 1940-84

Kirk A. Astroth
Neil C. Frischknecht

PESTICIDE PRECAUTIONARY STATEMENT

This publication reports research involving pesticides. It does not contain recommendations for their use, nor does it imply that the uses discussed here have been registered. All uses of pesticides must be registered by appropriate State and/or Federal agencies before they can be recommended.

CAUTION: Pesticides can be injurious to humans, domestic animals, desirable plants, and fish or other wildlife—if they are not handled or applied properly. Use all pesticides selectively and carefully. Follow recommended practices for the disposal of surplus pesticides and pesticide containers.

PROTECT

Use Pesticides Safely

FOLLOW THE LABEL

U.S. DEPARTMENT OF AGRICULTURE

PREFACE

The Benmore Experimental Range in north-central Utah was set aside for rangeland research in the 1930's because it was representative of vast areas of land that needed rehabilitation and improved management. These lands, originally in native sagebrush-grass vegetation, were important sources of livestock forage in spring and fall. Their value had declined seriously. Unregulated use and overuse had caused preferred grasses and forbs to decline and unpalatable shrubs to increase. Research was undertaken to find practical ways of rehabilitating and managing these lands.

Over a 44-year period, the Forest Service, Utah State University, the Soil Conservation Service, and others conducted many studies at Benmore—mostly on vegetation and livestock. The results have been documented in over 80 reports cited in this publication. Many of the findings can be applied to other parts of the Intermountain area with similar vegetation, soils, and climate.

This report provides rangeland managers and users with a summary of the 44 years of research at Benmore. This distillation of information may be helpful in planning and decisionmaking. It is a guide to research results—recognizing that rangeland managers and users have neither ready access to the literature nor the time necessary to search it. Those who want more detailed information can follow up with specific reports cited in the References section.

We hope that managers and users of western rangelands will find this a useful reference.

ACKNOWLEDGMENTS

This publication was developed under an agreement with the Utah Department of Agriculture and was conducted through the active cooperation of the Range Science Department, Utah State University. It was partially funded by a grant from the Four Corners Regional Commission.

THE AUTHORS

KIRK A. ASTROTH has recently completed a master's program in range management at Utah State University in Logan. This publication is a result of his work there as a graduate research assistant in the Department of Range Science. He also earned a degree in political science from the University of Denver (1974) and an M.A. degree in political science with a concentration in comparative politics from Columbia University, New York (1976).

NEIL C. FRISCHKNECHT recently retired from the position of principal range scientist and team leader at the Intermountain Station's Shrub Sciences Laboratory in Provo, Utah. He earned B.S. and M.S. degrees at Utah State University and a Ph.D. degree from Brigham Young University. From 1962 until 1975 he was project leader for research in ecology and management of pinyon-juniper, sagebrush-grasses, and low shrub cold desert ranges. He was involved in the research program at Benmore during much of his 37-year career in Forest Service research.

RESEARCH SUMMARY

The Benmore Experimental Range was set aside, fenced, and seeded to improved grasses during the late 1930's. This land was typical of much of central Utah, which had been overgrazed by livestock or plowed, farmed, and abandoned. State and Federal agencies and local citizens saw a need for research to find better ways to rehabilitate, use, and conserve the vast areas of sagebrush-grass rangelands such as those at Benmore. Research began in 1941 under a cooperative agreement among the Forest Service, Utah Agricultural Experiment Station, Soil Conservation Service, and the Bureau of Plant Industry. During the 44 years of work summarized here, many researchers analyzed alternative ways of rehabilitating the land by controlling brush and planting improved grasses, controlling reinvasion by brush, managing rehabilitated lands, and controlling effects of grazing livestock. By following recommended practices, managers can successfully increase the productivity of the land and the livestock. The authors have summarized the findings of 44 years of research from over 80 separate research reports. Results of the Benmore experience can be used in planning and decisionmaking for Intermountain rangelands such as those of central Utah. Many of the findings about basic relationships and improvement of management methods may be useful in analyzing problems of other Intermountain rangelands. Management guidelines summarizing each major section of the report appear at the start of each section.

CONTENTS

Managing Intermountain Rangelands — Research on the Benmore Experimental Range, 1940-84

Kirk A. Astroth
Neil C. Frischknecht

INTRODUCTION

> The Benmore project is only a dot on the map in comparison to the vast acreage of rangeland surrounding it. On millions of acres of land in this state (Utah) alone, resources in the way of soil, sunshine, and moisture are being squandered in the production of sagebrush and a few other unpalatable plants. How long we . . . let this sort of thing continue depends not on our learning how to do the job, but only awaits the time when we will have developed the enterprise to take advantage of our opportunity.
>
> —Harry K. Woodward, 1948

Since the 1940's the science and art of range management has developed immensely. Notions once based on "horse sense" have been modified and refined over the years by practical experience and hard research. This research, conducted by a variety of agencies and groups, has helped increase our knowledge about how best to administer America's vast rangelands. The Benmore Experimental Range, for example, has been the location of numerous studies extending over four decades that explored techniques for improving western rangelands and how they can best contribute to livestock production. Despite these efforts, many thousands of acres of range are producing less than their potential—the result of years of abuse or neglect.

The condition of western rangelands has improved generally since the 1930's, but the task of rehabilitating our depleted rangelands is still a formidable one. Much of this land lies west of the Rocky Mountains where the climate is harsh for vegetative growth. In fact, 17 Western States comprise about 70 percent of America's rangelands—in all, over 700 million acres. Utah itself is a major range State with over 45 million acres of rangeland constituting nearly 86 percent of the State's land area. Of this range acreage, 36 million acres (80 percent) are publicly owned. Some of these lands are in need of rehabilitation and good management is paramount to high productivity.

Utah is not unique among Western States, however. Every state has rather large acreages of depleted rangelands that now support only a fraction of their former livestock numbers. Moreover, the scant vegetation on some areas is unable to prevent the erosion of valuable topsoil, increased flooding, loss of wildlife habitat, and declining range productivity.

This condition exists on both public and private rangelands. While many clearly recognize the importance of bringing lands into their potential to produce, few have known what proven methods to employ. In many cases, research findings have not been made readily available to managers. In other cases, the prospect of actually harming the range even further through improper management has led to an unwillingness to experiment. To range workers, grass is both the key to prosperity and a means of maintaining a stable livestock industry.

Even with good methods for restoring the West's depleted ranges, some disagreements stem from the characteristics of rangelands themselves. Some lands are difficult to manage because rainfall is low and erratic, and temperature extremes are often great. Rangelands that receive between 12 and 14 inches (30.5 and 35.6 cm) or more of annual precipitation can be reseeded with good success. The risks increase rather dramatically if precipitation falls below these levels.

But the ranges that receive adequate precipitation also receive the greatest pressure from livestock. Many of these ranges lie in the foothill areas and are grazed both in the spring and fall. These so-called spring-fall ranges not only receive grazing pressure at two times during the year, but the spring period also coincides with the time of greatest nutrient requirements when animals are nursing calves or lambs. Lack of green grass in the springtime, then, leads to nutritive deficiencies in livestock.

Prior to regulated grazing, competition for nutritious forage led to range wars and the deterioration of both spring and summer ranges by grazing these areas before plants had sufficient growth. Some range workers realized that if spring ranges could be reseeded with an early growing, grazing-tolerant grass, livestock and range alike would benefit. Not only would range productivity and condition improve, but conservation of soil and water, improvements in wildlife habitats, and reductions in flooding would also result.

The Benmore Experimental Range was established in the middle 1930's to address this need and develop sound range management techniques that would improve grazing capacities on foothill rangelands of the West.

ESTABLISHMENT AND ADMINISTRATION

The early history of the Benmore area shows that this land was unadapted to successful dry farming (see appendix A for history of Benmore). Its usefulness was limited to the grazing of livestock, and because it was in the spring-fall belt, research became a primary need. Such spring-fall areas were recognized as the limiting factor in successful range livestock production operations in Utah.

Twenty-eight 100-acre (40.5-ha) plots were set aside for fencing and seeding. In addition, a 280-acre (113.3-ha) holding pasture was established. Employees of the Works Progress Administration (WPA) built most of the facilities at the range station between 1935 and 1940. The facilities included a 5,000-gal (18,927-liter) storage tank, two storage reservoirs, pipelines to all 28 pastures, and a well. Finally, 160 acres (64.8 ha) were set aside for reseeding studies along with a 20-acre (8.1-ha) tract that would be left untreated to illustrate what had occurred on the abandoned dry farming lands.

The Benmore pastures remained unseeded until fall 1938 and spring 1939. The pastures were plowed, the sagebrush removed, and seed spread into light stands of cheatgrass in the following mixtures (see appendix B for a list of common and scientific names):

Type of seed	**Lb/acre (kg/ha)**
Crested wheatgrass	2.5 (2.80)
Smooth brome	1.0 (1.12)
Slender wheatgrass	0.5 (0.56)
Western wheatgrass	0.5 (0.56)
Tall oatgrass	0.5 (0.56)
Total	5.0 (5.60)

At a later date, bulbous wheatgrass was broadcast at a rate of 1 lb/acre (1.1 kg/ha). Of all these species, crested wheatgrass adapted best to conditions at Benmore. However, it was slow to establish on the pastures, perhaps because of the low initial application rate and because of competition from annual weeds (fig. 1). Thus, the poorest stands were later reseeded with crested wheatgrass at a rate of 4 lb/acre (4.5 kg/ha) in 1941 and some pastures even a second time in 1945. All stands were protected from grazing by domestic herbivores until 1943 when some stands were judged ready for use.

The Benmore seedings, then, represent some of the West's oldest crested wheatgrass stands. Presently, crested wheatgrass comprises about 95 percent of the available forage. Traces of bulbous bluegrass and western wheatgrass can be found as well as some perennial

Figure 1.—Perennial crested wheatgrass invades a patch of annual weeds, namely cheatgrass and Russian thistles.

forbs and various annuals. Big sagebrush and rubber rabbitbrush are present in varying amounts but eaten very little by cattle and then only in the fall.

In the late 1940's, Utah State University researchers seeded smaller pastures to Russian wildrye, and intermediate, tall, pubescent, and crested wheatgrasses. These comprised the area between the main road leading to Benmore and the larger crested wheatgrass pastures, as shown in figure 2.

During the 1930's, Benmore was shuffled between several administrative agencies. Some of these included the National Resources Committee, the National Resources Board, the Resettlement Administration, and the Bureau of Agricultural Economics. Finally, the area was turned over to the Soil Conservation Service for management until 1954 when the Forest Service acquired it.

From the beginning, a number of agencies cooperated to conduct research at the Benmore Experimental Range (Walker 1944). The Utah Agricultural Experiment Station, the Soil Conservation Service, the Forest Service's Intermountain Forest and Range Experiment Station, and the Bureau of Plant Industry in 1941 signed a cooperative agreement on the future of research at Benmore. Specifically, these organizations committed themselves to studying the rehabilitation of abandoned cultivated lands through reseeding, management, and conservation of soil and water, and to ascertaining "the best management methods and practices for such lands both during and after rehabilitation and restoration."

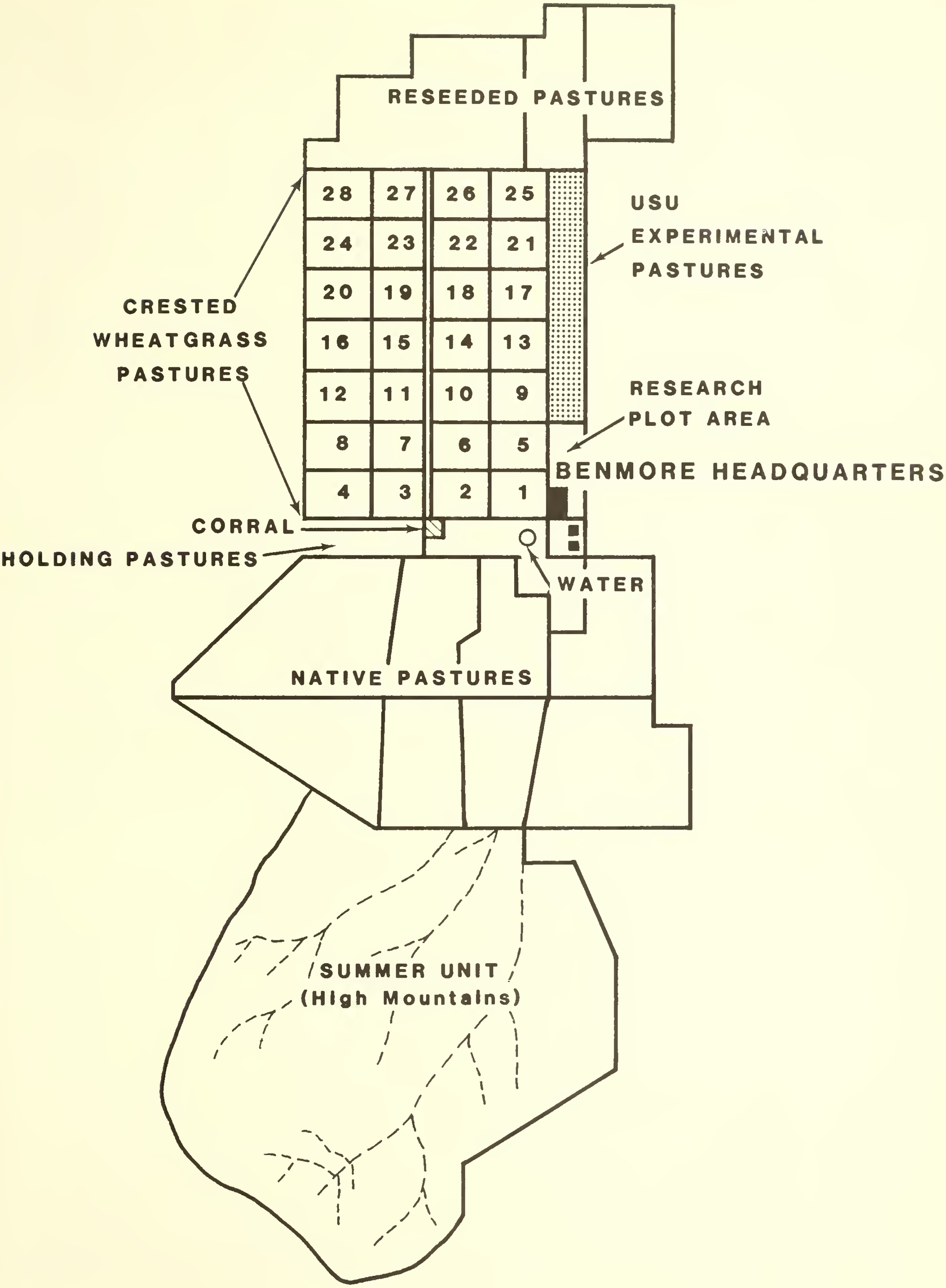


Figure 2.—Facilities at Benmore, Utah, include 28 reseeded crested wheatgrass pastures (water is piped to each), reseeded pastures, holding pastures, Utah State University seeded pastures, and native pastures and mountain pastures research plot areas.

SITE DESCRIPTION

Located in the southeast corner of Tooele County in Utah, the Benmore Experimental Range is in Rush Valley on typical spring-fall range (Frischknecht and Harris 1968). The experimental area lies between salt-desert shrub range to the north and mountainous summer ranges to the south and west.

The Benmore pastures are approximately 5,800 ft (1 768 m) in elevation and receive an annual average precipitation of approximately 13 inches (33 cm). Rainfall in Rush Valley is rather erratic and a high evaporation rate further reduces precipitation effectiveness. Since 1911, when recordkeeping began, Benmore has received a low precipitation level of 6.8 inches (17 cm) in 1956 and a high of 19.01 inches (48 cm) in 1913. Half the precipitation generally occurs between December and May while 40 percent falls during the growing season.

Benmore has an average annual temperature of 48.4° F (9.1° C) with a maximum of 61.5° F (16.4° C) and a minimum of 35.4° F (1.9° C). Generally, the first killing frost occurs by September 25 and the last by May 30. Summers are usually dry, hot, and windy.

Soils at Benmore are unconsolidated clay loams, light gray to pale brown, and calcareous. The organic content is relatively low, and there is a dense claypan layer found at about the 17-inch (43-cm) level. Upper horizons of the soil are moderately permeable. But because the soil is fine textured, it crusts over easily after a rain. Thus, seedlings can have difficulty penetrating this baked surface.

The topography at Benmore is generally level, but the area is dissected by intermittent channels and swales. Drainage is to the north on about a 2 percent slope and sheet erosion can be severe in the absence of sufficient plant cover.

Native vegetative growth in this area of Rush Valley is diverse. Grass species include bluebunch wheatgrass, Sandberg bluegrass, thickspike wheatgrass, western wheatgrass, Indian ricegrass, bottlebrush squirreltail, Great Basin wildrye, and annual cheatgrass. Forb species are equally diverse and those most prominent include lupine, Utah sweetvetch, longleaf phlox, hoary phlox, low fleabane, desert globemallow, groundsel, hawksbeard, false dandelion, locoweed, and annuals such as Russian thistle, pepperweed, and halogeton. Common woody species are big sagebrush, rubber rabbitbrush, yellowbrush, juniper, and some pinyon.

When it was purchased in 1934 under the Central Utah Dryland Adjustment Program, the Benmore Experimental Range was typical of thousands of acres of land in the Intermountain West that were producing little forage but were still used for grazing. Carrying capacities on these lands were extremely low, and available forage was of low quality.

When Benmore was established, range management on foothill ranges was still in its infancy, and little was known of range improvement techniques. Because the range had been broken up and native grasses had all but vanished, sagebrush had come to dominate vast areas of formerly prime grazing land. One early settler had experimented with burning, but more systematic studies of techniques were called for. In restoring depleted rangelands to grass, a number of problems would be encountered: clearing brush; preparing the soil; time, rate, depth, and method of seeding; adaptation of grass species; and method and intensity of grazing. The Benmore Experimental Range was ideal for investigating these questions.

REMOVING RANGELAND BRUSH

> Studies at Benmore may be taken as "a fair example of what may be expected from reseeded sagebrush lands in Utah if they are properly managed."
>
> —Lorin E. Harris and others 1950

Restoring deteriorated spring-fall rangelands is no simple task. Experience shows that perennial grasses seeded into dense stands of sagebrush or cheatgrass do not become established. The land must be properly cleared and the soil prepared before seeding. Otherwise, failures can result and grazing capacity may actually be reduced rather than increased. While it is possible to eliminate competing species with large machinery, such operations are limited to tillable land and are often costly. In addition, seed prices tend to be high and the probability of success often low, mitigating against trial-and-error efforts by livestock operators. Thus, results of experiments conducted at Benmore can be useful to ranchers and resource managers in many parts of the West.

Because the condition of the soil at seeding is critical, alternative methods of brush removal were extensively investigated at Benmore. These experiments were carried out to ascertain the best and least expensive methods of brush removal on shrub-dominated rangelands, including plowing, burning, harrowing or railing, the use of a brush cutter, and subsequently, spraying with herbicide.

Guidelines on Brush Removal

Reclaiming deteriorated rangelands or abandoned farmlands must begin with effective methods of brush removal. Because of the risks involved and the possibility of failure, methods that eliminate, as completely as possible, competing species should be employed. Based on experiments at Benmore, the following guidelines are suggested:

1. When deciding which lands to treat, managers should choose the best for the initial treatment: good soil, level topography, absence of trees.

2. If money permits, a brushland plow, wheatland plow, or offset disk will work best to eradicate brush species. For the latter, plowing should be done in two directions with the disks set at an angle.

3. Burning is an economical method of brush eradication and is highly effective given the right conditions. The weather should be dry, somewhat windy; there should be good ground fuel to carry the fire, and a wide fireline to stop the fire.

4. After treating an area (either by mechanical or natural means), it should be rested at least until the fall of the second growing season before any grazing is allowed. This will enable perennial grasses to establish

themselves to compete effectively with other less desirable species.

Site Preparation

Mechanical methods.—These methods, including disk plows, wheatland plows, and offset harrows have all been tested at Benmore with varying degrees of success. Early experiments with cheatgrass reported by Stoddart (Benmore Field Day Report 1947, unpublished) indicated that disking with a wheatland plow in fall after seed germination resulted in complete eradication of cheatgrass. Disking in summer and late spring were both effective in reducing cheatgrass stands, but less so than fall disking.

On sagebrush, Stoddart found that disking one way with the disks set straight gave only 35 percent sagebrush kill but disturbed soil only to a minimum. Disking two ways with the disks set at an angle resulted in 95 percent sagebrush eradication.

Stoddart (Benmore Field Day Report 1947, unpublished) found that railing twice kills less brush than heavy plowing; a 50 percent kill is about average. Similar results were also found for the log harrow. Stewart (Benmore Field Day Report 1947, unpublished) reported that rabbitbrush was not so completely killed by railing, plowing, or burning as was sagebrush. It sprouts readily and tends to become a major nuisance in reseeded areas. Rabbitbrush also readily invades thin stands of grass.

In later experiments reported by Cook (1966a), disking one way eliminated only 80 percent of the sagebrush, but plowing twice using either a two-way offset or a wheatland plow killed nearly all the sagebrush on the plots. After two growing seasons, sagebrush cover on these latter plots was only 0.3 percent. The brushland plow developed by the USDA Forest Service from the Australian stump-jump plow controlled sagebrush in one operation.

Cook also found that shredding with a roto-beater and roto-knives was effective in controlling large sagebrush plants but not in eliminating the smaller ones. After 5 years, sagebrush had reestablished itself on these plots to comprise 25 percent of the cover.

Frischknecht (1978b) also reported that a Servis brush cutter was effective in killing large sagebrush plants, but small plants and those with prostrate branches survived. Seventeen years later it was difficult to distinguish between the treated and untreated plots.

On larger species, such as pinyon and juniper, chaining can be used. While this method is effective in removing these species, it is costly and should be employed only on thick stands of trees where the expenditures for such range improvements may be justified. Generally, chained areas also must be piled and then plowed or drilled for most complete removal of trees. Results of some chaining research conducted at Benmore were reported by Parker (1971) and Parker and Frischknecht (unpublished report).

Burning.—Treating depleted rangelands with fire is probably the cheapest method of brush removal, but it also poses problems. Brush is hard to burn if small, when spaced far apart, and when ground fuel is sparse or absent. Fire may destroy more than what was intended, eliminating both desirable and undesirable plants. Fire can also aid the invasion of undesirable plants, such as rabbitbrush and snakeweed. If the fire does not carry well, the removal of undesirable species may not be complete enough to permit successful reseeding of perennial grasses. Finally, the effort requires careful planning and management to avoid delay in the effort. Reliable firelines, workers to control spot fires, and a permit from the fire warden are required in most cases.

Burning experiments of various kinds have been conducted at the Benmore Experimental Range with varying degrees of success. Such experiments were initiated because of the high costs of other methods of brush removal and because many researchers have speculated that natural fire controlled the range of woody species and maintained the grasslands the early American pioneers reported finding.

Burning cheatgrass with a flame thrower before seed formation dramatically reduced the stand of this annual, according to Stoddart (Benmore Field Day Report 1947, unpublished). Natural burning in the early spring (mid-June) was much less effective than burning with a flame thrower because natural burning cannot be done until after the seed has developed enough to germinate. Burning before the seed is formed is difficult because the plants are still partially green, which requires special flame burners. However, early burning was, without exception, more effective than later burnings. Early summer burning (early July) had but slight effect on cheatgrass. Early August burning was somewhat effective probably because of a hotter fire, and material reduction was noted on the trial plots. Fall burning (October) did not reduce cheatgrass stands the following spring.

Stoddart reported that burning is one of the best and most cost-effective means of removing sagebrush. The ash fertilizer left after the burn was also a good seedling booster. Almost complete eradication was obtained during good burning weather. From his observations, June 30 was about the first date that sagebrush could be burned with good results. Depending upon the year, complete burns are then possible from that date until about October 1. Adequate wind, especially, was a critical factor in achieving a good burn. Stoddart reported that even in midsummer burning was impossible before 9 or 10 a.m. because winds were only slight.

Frischknecht (unpublished report), in cooperation with the Wasatch National Forest, conducted experimental burns to control sagebrush and invading junipers on native range at Benmore. Conditions are shown in table 1. The West Dutch burn on September 17, 1970, was conducted about 1 month later than had been planned because of the high hazard of burning in August. Conditions at the time of burning were not adequate for a thorough burn on big sagebrush. Ovendry weight of sagebrush leaves and flower stalks was only 44 percent compared to between 68 and 78 percent ovendry weight for various grasses and 53 percent for broom snakeweed. Good burns were obtained in draws, but the fire died out on ridges where grass cover was less dense.

Table 1.—Burning conditions for three prescribed burns at Benmore

Name of burn	Date	Beginning p.m. time	Temperature	Percent relative humidity	Windspeed
West Dutch	9/17/70	3:00	70° F (21° C)	27	0- 6 m/h (0-9.7 km/h)
Middle Dutch	8/24/71	4:30	82° F (28° C)	23	0- 5 m/h (0-8.1 km/h)
East Dutch	8/22/72	2:00	84° F (29° C)	14	12-15 m/h (19.3-24.1 km/h)

Prior to burning, density of invading junipers averaged 73 trees per acre (180/ha) on permanent plots 0.1 acre (0.04 ha) in size. Twenty-four of 60 (40 percent) permanent plots were unburned. However, 32 percent of the trees under 8 ft (2.4 m) tall burned, compared to only 19 percent of the trees over 8 ft.

In 1971, air temperatures and relative humidity were more conducive to burning the Middle Dutch area than the previous year on West Dutch, but light wind was once again limiting a complete burn. Because of light wind, a center firing method was used in hopes of creating a convection column that would draw fire in from the perimeter (fig. 3). Although, a good convection column developed, parts of some ridges did not burn.

The most complete burn was on August 22, 1972, on 350 acres (141.6 ha) known as East Dutch. Although 0.40 inch (1.02 cm) precipitation had fallen the night of August 18, by burning time on August 22 the fine fuel moisture was 6 percent, air temperature 84° F (29° C), relative humidity 14 percent, and windspeed 12 miles per hour (19.3 km/h) from the southwest. At 1 p.m., winds were from the north at 12 miles per hour, and skies were clear. By 1:30 p.m., a cloud cover appeared over the Sheeprock Mountains to the south, and winds shifted down-mountain from that direction. Crews had been prepared to fire the area with hand torches from the north, but when the wind suddenly shifted, crews proceeded to touch fire to the area along the south and west sides, beginning at the southwest corner of the area at 2 p.m. (fig. 3). Within 45 minutes, the entire area had been burned over. All trees on permanent plots were killed.

From this experience, Frischknecht established requirements for successful burning of sagebrush grass ranges where junipers are invading: less than 20 percent humidity, temperature 80° to 95° F (27° to 35° C), and windspeed 10 to 15 miles per hour (16.1 to 24 km/h). Under these conditions, good fire lanes were required, and control crews were necessary to control spot fires that might arise from fire whirls carrying firebrands across the fire lanes.

More extensive studies were started when many persons claimed that pinyon, juniper, and other brushy species had extended their range since settlement because of human interference with natural fires. Some have even estimated that Utah's pinyon-juniper cover has increased in the sagebrush-grass communities and now comprises about 30 percent of the entire State. Left unchecked, these woody species invade the lower sites and compete with grasses that provide the vast bulk of


(A)


(B)

Figure 3.—(A) A convection column was developed by center firing under conditions of very light wind on Middle Dutch burn. (B) Winds of 12 to 15 mi/h (19.3 to 24.1 km/h) resulted in a rapid, more complete burn on East Dutch.

forage for domestic and wild herbivores. Thus, Barney and Frischknecht (1974) examined vegetation on 28 burns of various ages and determined the successional patterns following a fire. The data collected, it was believed, would help range managers understand both the role of fire in the ecosystem and rates of invasion by various plant species.

The results of Barney and Frischknecht's survey suggest a number of ways that fire can be an important aspect of range improvement techniques:

1. The cover value for both cheatgrass and annual forbs was highest immediately after a burn, but then declined the first 22 years after the original burn. From then on, their percentage in the composition remained fairly constant and rather low.

2. Without artificial reseeding, perennial grass (usually western wheatgrass and bluebunch wheatgrass) tended to increase rapidly the first 5 or 6 years after a burn, to maintain a consistent level over the next 40 years, and then to decline as woody species increased. The lowest grass cover was observed in the oldest burns. As expected, there was a direct correlation between an increase in juniper tree cover and a decrease in grass cover over time.

3. Sagebrush occurred on all burns, regardless of the age, indicating that it can reinvade rather quickly following a fire if a seed source is nearby.

4. Trees take somewhat longer to establish themselves, remaining absent on burns for about 5 years, except for a few young plants. These plants, moreover, were found under or adjacent to crowns of trees that had been killed by fire—indicating that they probably originated from residual seeds.

5. The rate of invasion for trees was slower in young stands having few seed-producing trees at the time of the fire. Most trees became established from residual seeds soon after a fire originated. These researchers concluded that rates of shrub invasion and succession are also influenced by other factors not directly observed on the burn sites. For example, the rate of succession depends on the kinds and number of seed-dispersing agents—of which water and animals are the most important. Succession would be slow if it were only accomplished from the burn edge. This is especially true for large burns.

In addition, large herbivores can exert a strong influence on the rate of shrub invasion. Heavy grazing following a fire, as a Benmore settler noticed in the 1920's, will reduce the vigor and cover of perennial grasses and increase the invasion of woody species. Trampling by animals is also a factor in planting viable juniper seeds, although a minor one.

On the basis of this study, fire can be a valuable management tool to restore shrub-dominated rangelands at low cost. Although a burned area may initially be dominated by cheatgrass and other annuals, perennial grasses will establish themselves and remain vigorous for about 40 years (fig. 4). Trees begin to dominate burn areas after this time and eventually crowd out all but a few grasses. Even sagebrush can be crowded out by pinyon and juniper trees.

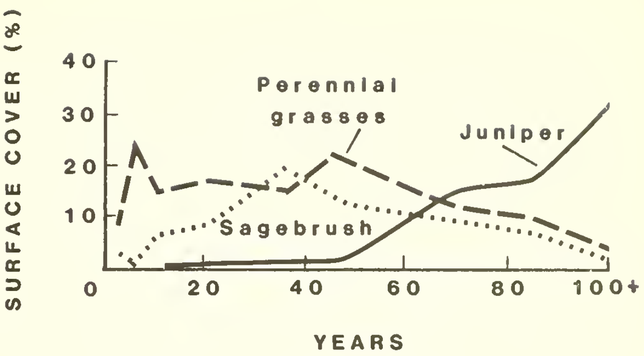


Figure 4.—Surface cover of juniper, perennial grasses, and sagebrush by age of burn (after Barney and Frischknecht 1974).

SEEDING RANGELANDS

As we have seen, research at Benmore helped develop brush removal practices that were economically sound and effective. However, at the time Benmore was established, little information was available about proper methods of reseeding depleted rangelands. Managers were unsure about what seeds would do best and provide good forage for domestic livestock. Obviously, there was a pressing need for data that would serve as a guide for successful management. Benmore was an ideal testing site to explore these problems.

During the 1930's vast areas of the West were being reseeded with an introduced grass known as crested wheatgrass. As a contribution to the western livestock industry, crested wheatgrass has been the forage discovery of the past century. It is remarkably free from diseases such as stem rust and ergot, and is ready for grazing as much as 3 weeks before cheatgrass. It is also winter hardy and not known to show frost injury (Benmore Field Day Report 1949, unpublished). Introduced from Eurasian Russia, crested wheatgrass adapts to the arid and semiarid conditions of the Western United States. Its abundant and nutritive growth from April until the end of June, and the greening characteristics it shows in September, October, and November following late summer or fall rains, make it admirably suited to restore spring-fall ranges depleted by abuses. In addition, by seeding crested wheatgrass and other grasses on depleted lands, especially dry spring-fall ranges, it is possible to keep a great many livestock off the higher ranges in the mountains until the vegetation there is ready to be grazed.

Guidelines on Seeding

Since 1942 studies at Benmore have sought the best methods of developing spring ranges for the Intermountain West. Some studies have focused on methods of seeding: time, rate, depth, and manner of seeding. Although research at Benmore has pointed to some successful techniques for restoring depleted ranges, there is no simple "cookbook" approach that will work

in all areas. Climatic, soil, topographic, and weed competition considerations must be recognized. However, the studies suggest the following guidelines:

1. Crested wheatgrass produces the best forage stands, is preferred by cattle in the early spring, and remains vigorous over long periods.

2. Plowing twice with an off-set disk eradicates nearly all sagebrush. When done in the fall, it results in higher rates of emergence and survival for all perennial species. A hazard of fall plowing, especially late fall near sagebrush seed maturity, is the likelihood of a new crop of sagebrush plants the following spring (Frischknecht and Bleak 1957).

3. Broadcast seeding prior to sagebrush eradication produces its best results in the fall, but drilling is superior when done in the spring (March 15 to April 15). A semideep furrow drill proves to be the best of all methods tested.

4. The soils should be firm and moist before drilling to produce the best results. In addition, seeds should be planted no more than 1 inch (2.5 cm) in depth. Drilling should never follow immediately after plowing on spring seedings, but has proven successful in the fall if not seeded too deep.

5. Emergence and survival rates will often be low. One should not expect more than 5 percent of the seeds planted to result in established plants 3 years later. Crested wheatgrass has an especially low establishment rate but has a high survivability rate thereafter.

6. Seeding should be done in moderate intensities (4 to 6 lb/acre or 4.5 to 6.7 kg/ha) and in moderate densities (drill rows 14 to 21 inches or 35.6 to 53.3 cm apart) to produce the best results. Such intensities will reduce invasion of annuals, ensure deep root development, lower plant fiber content, and produce thick stands that are preferred by cattle.

7. Contrary to earlier beliefs, mixed grass seedings should be avoided. Rather, pastures should be planted with one type of grass, and then cattle can be rotated among pastures as the season and palatability change.

8. If seed production is a consideration, presowing vernalization can help achieve flowering from spring planting the first year. It also can speed spring emergence and improve survival rates, which is probably more important than increased seed production.

Best Seeding Circumstances

Two studies by Cook and Stoddart (1947) demonstrated that reseeding depleted rangelands once dominated by sagebrush is not only feasible but can be very successful. The researchers concluded:

1. There must be a firm seedbed; after plowing, the ground should be allowed to sit several weeks before drilling, otherwise the loose soil tends to bury the seed too deeply during drilling.

2. The best time to seed in the spring appears to be after a rain storm so the ground is firm and moist, preferably in early April.

3. Seed should be no more than 1.5 inches (3.8 cm) deep, and preferably only 1 inch (2.5 cm) deep, especially seeds such as crested wheatgrass.

4. About 2 years must be allowed for these new stands to establish themselves before grazing can be permitted.

Cook and Stoddart's (1947) first study, initiated in 1943, used two species: crested wheatgrass and western wheatgrass. These two species were planted in all possible combinations involving early-fall, late-fall, and spring-season planting; high, medium, and low intensity; shallow and medium depth; and by using both an ordinary and a deep-furrow range drill for seeding. All seeding was done on fallow ground.

Analysis of these seedings in 1947 revealed some surprising results:

1. Spring seeding, in all cases, was superior to any other time of year, producing about 30 to 50 percent more grass.

2. The deep-furrow drill was distinctly superior to the ordinary grain drill, yielding about one-third to one-half more grass.

3. Crested wheatgrass produced better stands than western wheatgrass under all treatments at Benmore.

4. Planting depths of 1 to 1.5 inches (2.5 to 3.8 cm) gave about the same yields as more shallow plantings of 0.5 inch (1.3 cm).

5. Seeding at high intensity (7 to 9 lb/acre or 7.9 to 10.1 kg/ha) produced higher yields than at low intensity (4 to 6 lb/acre or 4.5 to 6.7 kg/ha), but the differences were not significant.

Not content to rest with these findings, Cook and Stoddart (1950) conducted a second study from 1944 to 1945 to observe other species and test different methods of planting. Three species of grass were used: tall, intermediate, and pubescent wheatgrass. Again, plantings were made in both spring and fall at shallow and medium depths and at low and medium intensities. This study revealed:

1. The best stands were produced first by pubescent wheatgrass and next by tall, with intermediate last.

2. All species produced excellent stands under the proper seeding methods, but pubescent and intermediate may produce denser stands because they form a sod. Tall wheatgrass is a larger plant and can yield an equal amount of forage overall.

3. Mixtures of early and late growing species would produce a pasture with a longer grazing season than monocultures.

4. Shallow planting and high density seeding generally gave better results than did deep planting and low intensity, but again, the differences were not great.

5. Early spring planting far outyielded fall planting and resulted in nearly three times as many plants in all treatments.

Seeding Techniques

The studies only began to address some of the important research questions posed by range rehabilitation. Cook and Stoddart (1950) then designed studies on seeding methods and concluded from them:

1. Fall broadcasting gives results comparable or sometimes even better than drilling, and at a lower cost.

2. Broadcasting must be done correctly and in conjunction with some effective means of brush removal, preferable plowing.

3. Drilling of seed in the spring, especially with the semideep furrow drill, produces better results than broadcasting.

Broadcast seeding.—One seeding study was designed to test three methods of brush eradication followed by broadcast seeding of four species of grass: crested, tall, intermediate, and pubescent wheatgrass. Sagebrush was treated by a wheatland plow, tumbling-log harrow, and rail. The rationale for testing broadcast seeding was twofold: drilling is expensive and broadcasting can be used on a variety of landscapes.

Overall, when all treatments and all plantings (fall or spring) were considered, all species produced about the same percentage emergence, ranging from 17.4 for tall wheatgrass to 20.8 for intermediate. In addition, all species under all methods of broadcasting produced higher emergence rates from the fall seeding during the first year. However, the results from subsequent years were variable, so in some cases the spring seeding produced as well as the fall seeding. From this study, Cook and Stoddart also identified the following:

1. Broadcast seeding before sagebrush eradication produced better results than broadcasting after for both spring and fall plantings for all species except crested wheatgrass on plowed land. Again, it appeared that too much soil fell back over these smaller seeds before germination.

2. During the first season, crested wheatgrass produced better results from fall seeding than any of the other species. However, during the next year (1948 to 1949) all species seemed equally well adapted to fall seeding.

The differences apparently were due to climatic factors. The first year of the experiment there were no spring rains to settle the soil. During the second year, spring rains made seedling emergence more likely. Thus, a variety of factors may influence the results of reseeding rangelands: species of grass, weather, method of brush eradication, and method of planting.

Drilling seed.—To test the latter variable to a greater extent, Cook and Stoddart (1950) initiated another study on the Benmore plots. The four varieties of wheatgrasses previously tested were again used but were planted with three types of drills on plots that had been (1) disk-plowed 1 month prior to planting, (2) disk-plowed 1 year prior to planting, and (3) railed 1 year prior to planting. The three types of drills used were the unitiller, the surface drill, and the semideep furrow drill. The comparative results:

1. The semideep furrow drill produced the best results under all conditions. The unitiller produced the poorest results, especially for crested wheatgrass seed. Again, the unitiller allowed too much soil to cover the seed for successful seedling emergence.

2. Plowing during the summer before fall planting was superior to plowing or railing a year earlier without further treatment to control annual weeds. Railing also produced the poorest results.

Seedling Emergence Rates

Cook and Stoddart (1951) reported on seedling emergence after different methods of soil preparation and planting. Three methods of brush eradication (plowing, railing, and tumbling log harrow) were used with fall and spring broadcasting of the four varieties of wheatgrasses. Emergence rates for seeds ranged from 3.65 percent for pubescent wheatgrass to 5.0 percent for crested wheatgrass. Again, fall broadcasting produced higher emergence rates than did spring seeding. Moreover, the method of brush removal directly affected overall seedling survival rates, which appeared to be correlated with the number of brushy species remaining:

Method of brush removal	Percent kill rate	Percent seedling survival
Plowing	95	52
Railing	40	26
Log harrow	40	19

In spring 1949, Cook and Stoddart (1951) set out to determine the effects of soil firming on seedling emergence. Again, the four species of wheatgrass were planted by five methods on sagebrush range—one half cleared by plowing, the other half by railing. One series of plots was then firmed with a cultipacker previous to and after planting. As expected, emergence was significantly greater for all four species on all plots that had been firmed by the cultipacker regardless of whether the seed had been drilled or broadcast. Emergence rates for firmed plots were 46 percent of the viable seed compared to 24 percent on the unfirmed plots. Again, the semideep furrow drill produced slightly better results than did the surface drill.

This study showed that there was no great difference in the percent emergence or survival among species by method of brush removal at the end of the first year. However, long-range results are often more important than immediate results. Seedling survival over the long term may be directly related to competing vegetation on an area the first summer. Plowing 1 month before planting appears to produce the best results. Moreover, while a firm seedbed is beneficial to seedling emergence, soils that are too fine in texture and too wet may compact to a hard crust and impede emergence.

Drilling of all seed types in the spring produced more than four times the number of seedlings than fall seeding. Yet, survival of fall seedlings was 40 percent compared with only 11 percent of the spring seedlings. Still, the higher emergence percentage on spring-planted plots resulted in higher numbers of established plants.

Cook and Stoddart determined that the average seedling emergence rate for all four species of wheatgrasses combined was only 11 percent. Of this number, only about one-fourth survived into the second season. Thus, even under proper methods of soil preparation and seeding, only about 3 percent of the viable seed planted actually became established plants by the third growing season.

Despite this low survival rate, in a few years crested wheatgrass and pubescent wheatgrass were closed stands.

Intermediate and tall wheatgrass at first produced good stands, but then began to show interspaces that filled with cheatgrass. The crested and pubescent wheatgrass stands were still good 15 years after the original seedings, but the other two stands were in only fair condition. While seedling success was highest for pubescent wheatgrass, production of all four species at the end of 3 years was 464 lb/acre (520.1 kg/ha) for crested, 404 lb/acre (452.8 kg/ha) for pubescent, 333 lb/acre (373.3 kg/ha) for tall, and 304 lb/acre (340.8 kg/ha) for intermediate wheatgrass.

Intensity and Density of Seeding

With some of the questions about time and depth of seeding investigated, researchers then focused on intensity and density of seeding. Knowing the optimums, the most economical and efficient use could be made of seed on depleted rangelands. Leonard (1964) and Cook and others (1967) conducted separate studies over 9 years on grass stands with different seeding rates. Four wheatgrass species were studied: crested, pubescent, tall, and intermediate. Seeds of these species were planted in both fall and spring. In addition, four intensities of seeding were combined with four densities (row spacings) to derive 16 rates of seeding.

Intensities, per 25 linear feet (7.6m) of drill row:

Low	= 161 seeds
Medium	= 322 seeds
High	= 483 seeds
Very high	= 644 seeds

Densities (row spacing):

Low	= 28 inches (71.1 cm)
Medium	= 21 inches (53.3 cm)
High	= 14 inches (35.6 cm)
Thick	= 7 inches (17.8 cm)

Germination.—On the average, Leonard (1964) and Cook and others (1967) found that fall was the best for broadcast seeding and early spring best for drilling. The 2-year studies found that an average of 4.7 percent of viable seeds planted in the fall emerged as seedlings the following spring. Of 100 seeds planted in the spring, 12.8 seedlings emerged. Crested wheatgrass rates of emergence were significantly lower than the other three species for both seasons, averaging only four seedlings per 100 seeds. Other species averaged about 10 seedlings per 100 seeds.

In fall plantings, the number of established plants per 100 viable seeds decreased as row spacing became wider. Spring plantings demonstrated the same tendency, except for the 28-inch (71.1-cm) spacing, which resulted in somewhat higher numbers of established plants than did the 21-inch (53.3-cm) spacing. Reasons for this deviation are not clear. Tall wheatgrass was found to do much better when planted in the spring under all intensities and spacings. It produced 2.5 times as many plants in the spring compared to the fall.

All varieties of seed were also placed in a germinator to monitor overall germination potential. After 5 days, intermediate wheatgrass germinated 73 percent of the seed compared to pubescent with 70 percent, tall with 66 percent, and crested wheatgrass with only 30 percent. However, after 20 days in the germinator, these differences largely disappeared.

For field conditions, these researchers reported that thin stands seemed to experience higher germination rates (nearly 60 percent) compared to thick stands (55.4 percent), although these differences were not large.

Both Leonard (1964) and Cook and others (1967) noted that some seeds that did not emerge in the first spring season were lost due to early emergence in the fall and subsequent winter kill or seed rot. In addition, some seeds were also consumed by birds, insects, or rodents.

Although the results are not conclusive, fall plantings appeared to have a higher percentage of emergence when the drill rows were closely spaced. Spring seeds demonstrated similar tendencies except for the least dense spacing—28 inches (71.1 cm)—which exhibited the same percentage of emergence as the most dense. Why this should occur is not clear. On the average, only 8.7 percent of the seeds planted ever emerged. Moreover, this study noted that increased density of seeding or intensity of seed within the drill row decreased the percent of seed that produced established plants the first year. This conclusion was true for all four species and for both seasons of planting. Hence, there appeared to be competition between seedlings within the drill rows. Overall, then, seeding intensity appeared to have a greater effect on stand density over time than drill row spacing. This finding suggests that seeds planted in widely spaced rows will not produce a closed community as rapidly as the same quantity of seed planted in narrowly spaced rows.

Of the fall-planted seeds, an average of 20 percent germinated but did not emerge. For spring-planted seeds, the figure was 27.4 percent. Crested wheatgrass also demonstrated a greater tendency toward rotting in spring plantings than in fall plantings. The other three species rotted more in the fall. The average for all four species for rotting was 9 percent. In all cases, more ungerminated seeds were recovered from those planted in the spring.

Generally, there was a lower survival rate the more intense the seeding, although there may have been more total plants per plots due to the heavier seeding rate. As the number of seeds planted per unit of drill row increased, the number of plants that became established per 100 viable seeds planted decreased. This relationship was true for all four species and times of planting. Competition between seedlings did not affect germination but did affect growth and survival.

Herbage production.—Average herbage yield for all intensities and densities was 452 lb/acre (506.6 kg/ha) of air-dry herbage. The best results, of course, occurred when precipitation was higher than normal: 1951 to 1952 and 1954 to 1955. Yet, the general effect of season on yields was not that significant. Tall wheatgrass produced more from spring plantings at all intensities. Crested wheatgrass produced the most herbage of all varieties after three seasons, whereas tall wheatgrass produced the least, perhaps because the site was too dry for tall wheatgrass. As expected, high intensity and close drill row spacing produced the most herbage

per acre at the end of three seasons. Conversely, forage production decreased when a given volume of seed was spread out over a larger area.

Survival of established seedlings from the first season into the second year depended upon competition for moisture and drill row spacing. Average rates of survival for intensity and density into the second year were about 50 percent, but varied as widely as 30 percent for those planted in the fall to 68 percent for those planted in the spring. Analyzed by season of planting for all four species combined, on the average 53.2 percent of the first-year plants from seed planted in the fall survived into the second season. Only 20.3 percent of the first-year plants from spring planted seeds survived into the second year. The earlier germination of the fall planted seeds appeared to help these plants get established before the summer dry periods developed.

When expressed as a percent of seeds originally planted, the second-year survival rates are not impressive. Spring plantings averaged only 3.6 percent compared to 2.5 percent for seeds planted in the fall.

For individual species, though, the results are more illuminating. Crested wheatgrass had the highest percent survival rate into the second year (58.5 percent of plants present the first year). Yet, this species also had the lowest percentage of germination:

Species	Percent established 2d year
Pubescent	3.8
Intermediate	3.1
Tall	2.9
Crested	2.4

In addition, these studies noted a decline in the survival rates between the first and the second years with an increase in drill row spacing. Closer spacing may reduce competition from annuals and not induce severe competition between young perennial grasses. Yet, there is a limit. There appeared to be a lower survival rate the more intense the seeding.

Survival rates were also noted for the third season. Again, crested and pubescent wheatgrasses both exhibited the best survival rates. By the end of the third season, these two species had experienced only a 15 percent mortality rate over the second season compared to 30 percent for intermediate and tall wheatgrass. On the average, only 2.4 percent of the viable seeds planted the first year produced established plants by the third year. Therefore, any use should be light until after this period.

After three seasons, pubescent wheatgrass had the best stands with fewer annual weeds than the other species. Crested wheatgrass stands, however, were very comparable, and stand improvements from the third to the ninth season were, of course, greatest for both pubescent and crested wheatgrass. Tall and intermediate wheatgrass stands declined in quality over this period, and interspaces filled with annual weeds.

At the end of the ninth season, average production from the fall and spring plantings was approximately the same. Still, no plot was producing at its full potential. Moreover, regardless of species, fall plantings showed about twice as much brush invasion as plots planted in the spring. Why this result occurred is not clear.

Seedhead production.—Leonard (1964) and Cook and others (1967) found that the number of seeds per head and number of seedheads per plant were directly affected by stand density in young plantings. Thick stands produced 58.3 and 20.2 seedheads per plant for crested and tall wheatgrass, respectively. Thin stands, on the other hand, resulted in 121.5 and 33.5 seedheads for these two species, respectively. Seedheads were also longer (4.5 inch or 113.4 mm) in thin stands when compared to seedheads in thick stands (4.1 inch or 103.8 mm).

Soil moisture.—As in Leonard's study, Cook and others found no significant difference in the percent soil moisture between thin and thick stands. They concluded that lateral roots of grasses in both stand densities use moisture in equal amounts to at least an 18-inch (45.7-cm) depth. In addition, no significant differences were found in the depth of roots between thin and thick stands, numbers of roots per plant reaching maximum depth, or depth of root concentration.

Chemical content.—Plants in thin and thick stands differed in chemical composition. In thick stands, plants were somewhat higher in total protein, phosphorus, and total gross energy, while thin stands were slightly higher in lignin and cellulose concentrations. These differences were related to the leaf-to-stem ratio, which is directly influenced by stand density.

Utilization.—Intermediate wheatgrass was the most preferred grass all season long of the four species used. Livestock also showed a slight preference for thick stands over thin stands, 28 percent compared to 22 percent. These differences became more marked during late summer where preferences changed to 25 percent and 16 percent, respectively. Pubescent wheatgrass stands were not preferred by cattle under any circumstances.

During the mid-1960's, Cook (1966a) conducted further studies on the proper use and development of foothill ranges in Utah. He concluded that the highest potential land should be seeded first. In addition, a good species should be selected that, on the basis of research, can thrive under conditions for that site. As previous studies have demonstrated, crested wheatgrass is an adaptable species and produces good stands of herbage. Russian wildrye, while tolerant of salts in the soil, produces frail seedlings with high mortality rates. Seedings may require double the regular seeding rate if satisfactory stands are to be established.

Cook concluded that mixing grass species has not been the most desirable practice on foothill ranges because the stand soon converts to the species of lesser palatability. In contrast to studies that argued for mixed seeding, Cook concluded that it would be far better to rotate livestock among separately seeded pastures of pure stands.

He also observed that the method of brush eradication could ultimately determine the success or failure of any range rehabilitation project. Complete brush eradication by plowing prior to planting permits the seeded species

to reach full potential in about 5 years. Partial eradication requires additional herbicide treatments in 7 to 8 years, and the full potential of any site could be delayed for 10 to 11 years.

Based on studies at Benmore, Cook also surmised that drilling seed is superior to broadcasting it. The semideep furrow disk drill with 12- to 14-inch (30.5- to 35.6-cm) spacing was better than the ordinary single disk surface grain drills. Deep planting should be avoided. Cook also suggested that when 3 to 5 percent of the seeds remained uncovered and showing in or at the edge of the drill row, the seeds had not been drilled too deeply. Broadcasting works best when done in the fall prior to chaining, railing, or harrowing, but requires 70 percent more seed than drilling to obtain good stands the first time.

Cook (1966a) also reported results of research conducted on brush eradication and seeding methods. Plowing twice using either a two-way offset or wheatland plow removed nearly all sagebrush. The production figures in the fall for three species of wheatgrasses broadcast following these treatments are:

Species	**Production Lb/acre (kg/ha)**
Crested wheatgrass	841 (943)
Intermediate	574 (643)
Tall	507 (569)

Rates of sagebrush reinvasion for these plots was only 0.3 percent.

In trials at Benmore, Cook also found that plowing only once with a wheatland plow eliminated about 80 percent of the sagebrush, but sagebrush reinvaded at a much more rapid rate, resulting in progressively lower production figures. At the end of 3 and 5 years, the three species had the following yields that demonstrate this decline:

	Lb/acre (kg/ha)	
	3 years	**5 years**
Crested	621 (696)	273 (306)
Intermediate	689 (772)	307 (344)
Tall	604 (677)	167 (187)

On the other hand, plots that were treated with a brushland plow produced the following yields at 3- and 5-year intervals:

	Lb/acre (kg/ha)	
	3 years	**5 years**
Crested	628 (704)	1,199 (1 344)
Intermediate	400 (448)	821 (920)
Tall	464 (520)	834 (935)

On these plots, less than 0.5 percent of the ground cover was comprised of reinvading sagebrush.

Other Brush Treatments

Between 1947 and 1956, Cook (1958) conducted a related study on brush removal and planting techniques. This study had two objectives: (1) to gain further understanding about the effectiveness of various brush removal methods, and (2) to understand more about the effectiveness of broadcast seeding on soils that are rocky, steep, covered with small trees, or otherwise ill adapted to farm machinery. Cook concluded that the success of range reseeding operations is correlated with the method, season, and effectiveness of eradication and seeding following brush removal. Crested wheatgrass, when planted in the fall after plowing, produced the best stands over the 9-year study.

On experimental plots, sagebrush was removed by one of three methods: wheatland plow, Dixie log harrow, or railing. Treatments were applied in both the spring and fall. A whirlwind seeder was then used to broadcast the four grass species on experimental plots in both spring and fall.

Areas where plowing was used showed the least sagebrush reinvasion after 9 years—34 plants per 50-ft (15.2-m) transect line. All eradication methods seemed to be more effective in the fall than in the spring. For example, in the fall an average of 72 percent of the plants were eliminated under all treatments compared with 63 percent in the spring. In addition, a higher percentage increase of sagebrush occurred on areas treated in the spring over those areas treated in the fall.

Areas treated with the Dixie log harrow and then broadcast seeded supported the greatest number of seedlings after the first year, but over the entire 9-year study, the plowed areas produced more grass plants, and significantly more forage yield. By 1956, plowed areas were producing 183 lb/acre (205 kg/ha) compared to 110 lb/acre (123 kg/ha) for the harrowed areas—a difference of 60 percent.

Results for the four species of grass varied somewhat. Intermediate wheatgrass had the most plants on railed areas; the other species did best on plowed areas. Fall eradication of sagebrush and planting at the same season produced significantly higher numbers of seedlings of all four species than did spring treatments.

However, areas that were railed produced a greater number of seeded plants and more forage when this treatment was applied in the spring rather than in the fall. These results appeared to be related to the fact that sagebrush cover on spring-railed lands was only 49 percent compared to 83 percent on the fall-railed lands following treatment.

Broadcasting before sagebrush removal compared to seeding after removal produced a greater number of seedlings as well as a higher number of established plants and more forage of all species except crested wheatgrass. In this study, crested wheatgrass produced nearly the same results whether seeded before or after eradication of brush.

Differences in favor of broadcasting before sagebrush removal were less marked on plowed areas and were more marked when applied in spring than in fall. This finding may be due to vernalization of seed planted in the fall, whereas the seed planted in the spring lies exposed. Later studies investigate this contention.

Crested wheatgrass produced the highest number of seedlings per plot during the first growing season after treatments were applied. Intermediate wheatgrass produced the least. Yet, after 9 years, pubescent wheatgrass had a higher number of established plants per plot than

did the other grass species. Crested wheatgrass, because it produces a greater number of stems and leaves, produced more forage per acre than all other species even though this species had fewer total plants per plot. Tall wheatgrass, by contrast, produced the least amount of forage per acre and fewer established plants per plot.

Generally, then, Cook found crested wheatgrass and pubescent wheatgrass to be more adapted to broadcast seeding than were the other two species. Pubescent produced satisfactory stands under all methods during fall seeding but not in the spring. This finding held constant over the 9 years. Tall wheatgrass produced satisfactory stands when seeded in the fall and when broadcast before railing in the spring. However, stands of tall wheatgrass became less vigorous over the years.

Seed Vernalization Studies

Early studies suggested certain grass species responded better to fall planting than to spring planting. As a followup, Frischknecht (1959) examined the effectiveness of vernalizing different species of grasses. He concluded that vernalization could be accomplished in some species of perennial grasses through fall field planting or storage of soaked seed in a snowbank or refrigerator prior to spring planting. Thus, when fall plantings are not feasible, vernalization of some species should help to obtain successful grass stands from spring planting.

Frischknecht began his research after he had observed that certain species, particularly mountain rye, intermediate wheatgrass, and mountain brome, merely put out short shoots when planted in the spring, but produced flower culms and seed the first year when planted in late fall even though the seedlings did not germinate until spring.

Frischknecht selected seeds from eight perennial grasses, soaked these seeds for 20 hours at room temperature, and then buried the seeds in a snowbank for 50 days prior to planting. The species studied were mountain rye, two varieties of intermediate wheatgrass, pubescent wheatgrass, crested wheatgrass, fairway wheatgrass, tall wheatgrass, and Russian wildrye. These seeds were then planted at Benmore. Although none of the grasses produced seed the first year, the treated seeds emerged a few days earlier than the untreated seeds and produced culms in the first year. Thus, vernalization seemed to be beneficial to some species, resulting in greater culm elongation and increased survival of seedlings.

This researcher then designed another study to further investigate the effects of vernalization on perennial species of grasses. Using only four species—intermediate and crested wheatgrass, Great Basin wildrye, and Indian ricegrass, Frischknecht exposed these seeds to four different treatments:

—20 hours soaking at room temperature followed by storing in a snowbank for 48 days near 32° F (0° C).

—20 hours of soaking as above, followed by 48 days of extremely cold storage in a locker at near 0° F (−18° C).

—36 hours of soaking at room temperature followed by 3 days in the cold locker.

—36 hours of soaking at room temperature, but no cold treatment whatsoever.

Seeds were then tested for viability in a germinator. Only Indian ricegrass failed to germinate. Yet, there were differences in the responses of other species based on the type of treatment. Locker storage at near 0° F seriously reduced germination of the two wheatgrass species but did not affect Great Basin wildrye. Frischknecht hypothesized that Great Basin wildrye might have been metabolizing less rapidly than the wheatgrasses when placed in the cold storage locker because it is normally the slowest species to germinate. In addition, seeds of the two wheatgrasses soaked for 36 hours appeared to be more susceptible to damage by subsequent cold storage at 0° F than seeds soaked for 20 hours.

Except for Indian ricegrass, all grass species from snowbank storage began to emerge within 20 days after planting in the field at Benmore. There were also differences between species according to treatment. With intermediate wheatgrass, for example, seeds from both the snowbank storage and 36 hours soaked without cold treatments exhibited about equivalent emergence rates. But, the second year in the field, only intermediate wheatgrass from snowbank storage showed good stands of grass, although a few plants of this species survived from other treatments (fig. 5). Only a few crested wheatgrass plants were surviving in the second year, but none from the 48-day locker treatment. Some plants of this species flowered the first year, regardless of treatment. Thus, in crested wheatgrass the evidence indicates that vernalization treatment is unnecessary for first-year flowering in contrast to requirements for intermediate wheatgrass.

Frischknecht then devised a study to investigate how snow bank storage followed by spring planting compared with fall planting and refrigerator and snowbank storage. In this study, four species of grasses were used: crested and intermediate wheatgrass, Great Basin wildrye, and Indian ricegrass. All four species were planted in the fall in moist soil. In the spring of the following year, similar plantings were made but in three combinations: untreated seeds, soaked and stored in snow for 60 days,

Figure 5.—Plants from vernalized seed (rear) show better survival and development at Benmore in the second growing season than do plants from untreated seed (foreground).

soaked and stored in a refrigerator for 60 days at 31° to 34° F (−0.5° to 1.1° C).

All treatments generally produced germination rates superior to those of untreated spring-planted seeds. Snowbank-stored seeds did a little better than the other treatments, but the differences were minor. Weather and soil conditions, of course, can exert a strong influence on these results at any time.

Although most species Frischknecht studied could produce flowers the first year with or without cold treatments, higher rates of flowering did result when seeds were treated before spring planting. Cold treatments appeared to hasten spring emergence and aided survival of seedlings on dry sites. Therefore, where fall plantings are not feasible, vernalization should help to obtain successful grass stands. Some seeds of intermediate wheatgrass remained vernalized for at least 1 year when dried and stored in a basement after removal from a snowbank (fig. 6). This procedure may produce a crop of seed from spring planting a year earlier than otherwise, or increase seed yields the following year.

Figure 6.—Culm production in intermediate wheatgrass resulted from snowbank storage of seeds prior to planting. Treatments were, from left to right: (1) snowbank storage for 67 days; (2) snowbank storage for 60 days, dried 7 days; (3) snowbank storage for 38 days, dried and stored in basement for 1 year; and (4) untreated seeds.

MANAGING SEEDED RANGELANDS

With its purchase in 1934 under the Central Utah Purchase Project, the Benmore area was typical of thousands of acres of abandoned farmland that was producing little or no forage. Because range management was still in its infancy, little was known about the best methods of restoring grazing capacity on these lands. But another area of equal interest was how seeded lands could be managed to maintain their productivity. Because spring is the critical time for most livestock operations, research at Benmore concentrated on furnishing appreciable amounts of spring forage for large numbers of livestock. Cattle and sheep often come through the winter in poor condition. With feed on winter ranges scarce and summer ranges not ready, some animals die and low calf and lamb crops result. Good, high nutritive spring forage—an adjunct to larger calf and lamb crops as well as greater weaning weights—is often not available. Researchers hoped to ascertain the optimum level of grazing that would meet the animal's minimum requirements for growth and development and that also would maintain the vigor and productivity of the perennial grass stands.

The first seedings at Benmore, as mentioned in the previous section, demonstrated that crested wheatgrass could provide early spring forage for livestock. But how would it respond to grazing? This and related questions were the object of much research conducted on the seeded pastures in Rush Valley.

Guidelines on Management

The seeded pastures at Benmore are some of the oldest in the Intermountain West. Based on research, such stands can be maintained indefinitely and can provide valuable forage for livestock during much of the year under proper management techniques. The following are management guidelines:

1. Crested wheatgrass can supply excellent spring forage nearly 2 weeks earlier than most native grasses and fill an important need in livestock operations.
2. Pastures seeded with crested wheatgrass or the other introduced grasses can increase grazing capacities up to tenfold over depleted sagebrush-grass range.
3. Crested wheatgrass also demonstrates excellent fall regrowth potential during favorable years. It can supply forage for livestock during fall if not grazed heavily in spring.
4. Seeded foothill ranges reduce the grazing pressure on adjacent depleted or deteriorating ranges and can delay and shorten the grazing season on high mountain ranges, allowing their improvement.
5. Rather than planting mixed introduced grasses, pure stands of these species appear best. Grasses can then be grazed in order of maturity during the season: crested wheatgrass in the early spring, followed by tall wheatgrass, then intermediate wheatgrass, and finally Russian wildrye. Pubescent wheatgrass was not preferred by animals under most conditions. Under conditions similar to Benmore—13 inches (33 cm) annual precipitation—tall and intermediate wheatgrasses cannot be counted upon to maintain good stands indefinitely.
6. A rotational grazing system is best with use pegged at 60 to 65 percent of current year's growth of crested wheatgrass. This level will produce the highest total animal gains and maintain the forage resource as well as minimize shrub invasion. This level of use will also leave enough forage for fall grazing and will limit the number of wolf plants.
7. Fat livestock should be sold after coming off the summer ranges and only the breeding herd and stockers retained into the fall.
8. Late summer and fall grazing are feasible on mature growth of crested wheatgrass, especially when a protein supplement is provided. Under these conditions, livestock gains are comparable to gains on forest mountain lands. If native wheatgrass ranges are available, livestock will make excellent gains on these lands during the fall.

9. Sheep do not use the introduced grasses over long periods as well as do cattle. Sheep tend to suffer weight losses during the fall, especially where sagebrush is dense. They can be expected to about maintain their weight on crested wheatgrass under a stocking rate of 50 sheep days per acre in the fall where sagebrush has a density of about 1.5 plants of all sizes per 100 ft^2 (9.3 m^2).

Preliminary Studies

In 1943, the directors of the Benmore Experimental Range felt that the stands in some pastures were well established enough to permit limited fall grazing. To determine yields and grazing capacities, additional pastures were opened to both spring and fall grazing between 1944 and 1946. The first, rather limited study (Frischknecht and others, n.d.) sought to determine how crested wheatgrass should be managed for optimum production of forage and for sustained yields year after year. After 4 years, researchers found the following:

1. Crested wheatgrass was ready for grazing about 2 to 3 weeks earlier than native ranges.
2. Approximately 2.5 acres (1 ha) of crested wheatgrass would support one animal unit month (AUM), whereas 12 to 25 acres (4.9 to 10.1 ha) of depleted native range were necessary to support the same amount. Thus, planting crested wheatgrass on abandoned dryland farms could increase grazing capacities 10 times.
3. Gains per cow on the seeded pastures averaged 3 lb/day (1.4 kg/day) whereas cows gained only about half that much on depleted ranges.
4. Cattle that grazed on seeded pastures in the spring went onto summer ranges in excellent condition, whereas cattle that grazed on depleted native ranges went onto summer ranges in poor condition.
5. This increased grazing capacity on seeded spring ranges allowed resource managers to reduce grazing on depleted native ranges. With this reduction in grazing pressure, depleted native ranges began to show signs of recovery.
6. Crested wheatgrass also demonstrated a marked capacity for fall regrowth when rainfall was sufficient. Thus, its early readiness and fall regrowth potential allowed managers to shorten the season on summer ranges by as much as 2 months during most years. Hence, grazing pressure on mountain ranges was reduced and they too began to show signs of recovery.
7. The uniform breeding season for cattle on seeded ranges resulted in a 95 percent calf crop (fig. 7), compared to about 70 percent on unseeded ranges where bulls and cows were run together the entire grazing season. Most research indicates that breeding of yearling heifers is not a good practice and usually does not result in a higher calf crop.
8. Calves were generally in excellent condition on seeded ranges at weaning time and thus commanded top prices over calves grazed on adjacent native ranges.

These findings meant that real long-range economic gains were possible if depleted ranges were cleared and seeded to crested wheatgrass. However, this first study, was far from systematic or of sufficient duration to be reliable. In addition, there were still many questions: What levels of grazing should be maintained? How long can cattle be held on these seeded ranges before the nutritive value of the grass declines? What type of grazing system, if any, should be used? Obviously, more studies were needed.

Systems and Intensities of Grazing

In 1947, the cooperating agencies at Benmore initiated an 11-year study to determine the proper grazing of seeded rangelands (Frischknecht and Harris 1968). After some preliminary measurements, researchers began to test 12 combinations of methods of spring grazing. The methods combined four systems and three intensities of grazing:

Systems of grazing

1. **Rotation.** Each 100-acre (40.5-ha) pasture was divided into three units with the cattle shifted between them in regular order periodically. Each subunit was grazed twice during the 60-day spring grazing season (April 20-June 20).
2. **Continuous.** Pastures were grazed continuously for the 60-day grazing (April 20-June 20).
3. **Delayed.** Beginning of a 50-day grazing was delayed 10 days (May 1-June 20).
4. **Shortened.** Grazing terminated early after 50 days (April 20-June 10).

Figure 7.—Cows grazed on crested wheatgrass produce good calf crops and high weight gains.

Intensities of grazing

1. **Light:** grass use about 50 percent.
2. **Moderate:** use about 65 percent.
3. **Heavy:** use about 80 percent.

After monitoring these systems for 9 years, researchers reported that intensity of grazing appeared to exert a greater influence on vegetal changes than did the various seasonal systems of grazing. Hence, the researchers recommended that range managers closely monitor levels of use if grass stands are to remain productive. Frischknecht and Harris (1968) also concurred with the earlier Benmore results that recognized that crested wheatgrass could fill an important forage need for livestock in the early spring (April 20) to early summer (June 20). Crested wheatgrass was ready earlier than native ranges and was also highly nutritious during this period. Overall, this study determined that crested wheatgrass, when grazed at approximately 65 percent use, resulted in good cattle gains and healthy grass production.

Systems of grazing.—On the basis of this 11-year study, Frischknecht and Harris (1968) observed that delaying the start of the spring grazing system by 10 days contributed to maximum grass yields and increased the basal area of plants. On the other hand, shortening the end of the grazing season by 10 days contributed to increasing plant numbers. The researchers also reported that a good rule of thumb is to not graze the same area at the same time of the growing season each year. Resting the range periodically from spring grazing will improve the overall long-range vigor of the grass plants.

Frischknecht and Harris also found that the largest number of plants were present in pastures where rotation or shortened grazing was practiced. The fewest plants occurred where grazing was delayed 10 days in the early spring. In addition, rotational grazing or delayed grazing coupled with heavy levels of use maintained grass stands better than did the same level of use with continuous or shortened systems of grazing. However, the researchers did not find any significant differences in levels of digestible energy between the four systems of grazing. Rotational grazing did prove to be the best overall method of grazing cattle when all factors were taken into account (fig. 8).

Intensity of grazing.—Originally, the intention was to graze all pastures in both the spring and fall, but heavy levels of use left nothing for the fall and thus fall grazing was discontinued on all pastures. However, it was believed that pastures grazed at the light and moderate levels in the spring could be grazed again in the fall, given sufficient late-season precipitation. The results seem to substantiate this belief.

The lightest spring grazing left enough forage so that fall grazing was feasible on all pastures. Even at 65 percent use, enough forage remained for limited fall grazing. But at the heavy levels, little remained by fall and regrowth was not substantial (fig. 9).

In the pastures grazed at light intensities, a large number of wolf plants developed. Cows tended to avoid these plants year after year, unwilling to graze between

Figure 8.—Cows were moved to a moderately grazed pasture that is delimited by a two-wire electric fence.

dried stalks to get new growth. When subjected to heavy grazing, these plants were soon used, and under moderate grazing there was a gradual reduction in old growth plants.

Moreover, the greatest number of young plants occurred in lightly grazed pastures, whereas the fewest were in heavily grazed pastures. Researchers attributed this difference to reduced seed production in heavily grazed pastures, although the importance of seed production has not been demonstrated.

Heavily grazed pastures showed reduced grass yields while the other two treatments over time differed little in herbage production. Heavily grazed units exhibited more numerous and larger dead plant centers than the other treatments. Yet, when averaged over 11 years, heavy grazing produced more digestible energy than the light and only slightly less than the moderate treatments. This finding agrees with other studies that concluded that frequently clipped crested wheatgrass maintains a higher overall nutritive value than unclipped plants, in large part because of new growth shoots. Moreover, removal of 80 percent of the current year's growth year after year resulted in: (1) a decline in herbage production; (2) accelerated dying of grass plant centers; (3) little or no seed production; (4) excessive trampling of both soil and grass, which increased soil erosion and broke up plant crowns; (5) accelerated invasion of rubber rabbitbrush and big sagebrush; (6) heavier use of forage by rabbits because of the presence of brush cover; (7) invasion of annual weeds, cheatgrass, Russian thistle, and halogeton; and (8) no fall grazing except in years of abundant regrowth (that is, with high precipitation).

Finally, cattle days per acre, as expected, were highest for the heaviest intensity of use, but the carrying capacity per acre dropped considerably when compared to capacities for the light and medium intensities.

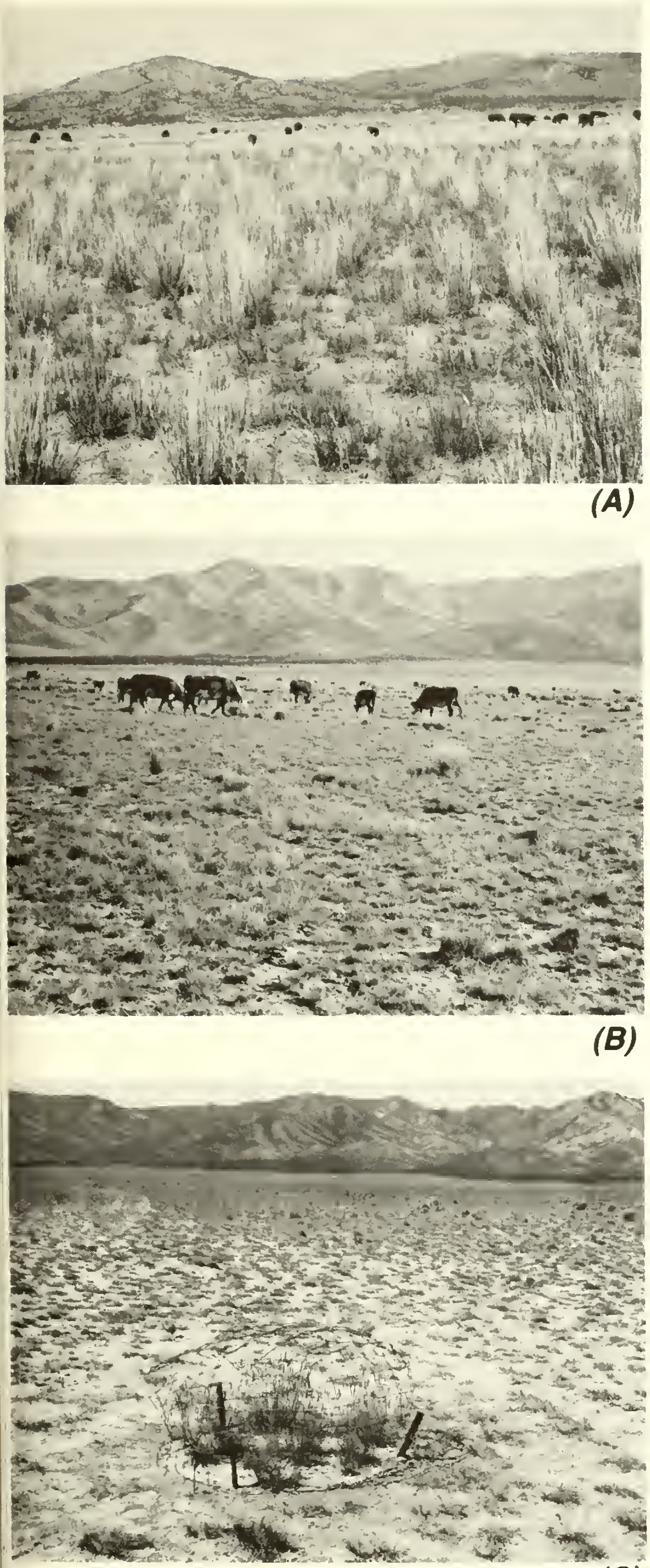


Figure 9.—(A) Lightly grazed pasture shows differential grazing and accumulation of old growth as a result of some plants being ungrazed each year. (B) Moderately grazed pasture shows fairly uniform use. (C) Wire cage protection plot covers an area slightly larger than 9.6 ft (0.9 m) in heavily grazed pasture.

Animal gains.—The results of the 12 combinations of grazing showed that rotational treatment produced the highest gains per acre during 7 of the 11 years, but the least on a daily basis. The reason for this difference is not clear, but researchers suggested that the short-term results may be related to the quality and quantity of forage at any one time. The system that removed cattle 10 days early from seeded pastures produced the lowest gains per acre in 7 of the 11 years of the study. However, because growth is most nutritious earlier, this system produced the highest daily gains over the 11 years.

Harris and others (1957) observed that the greatest gains for cattle occurred in the early spring and then decreased as crested wheatgrass matured. This finding is consistent with other studies showing that the nutritive value of crested wheatgrass and its palatability decline with seasonal maturity. By the first of July, cellulose and lignin levels are comparatively high, while protein and phosphorus are low.

Gains per acre were also dependent on the type of grazing system used and the grazing intensity, as shown in this summary:

System	**Gains in lb/acre (kg/ha)**
Rotation	42.9 (48.1)
Delayed 10 days	40.6 (45.6)
Continuous	39.0 (43.7)
Removed 10 days	37.3 (41.8)
Intensity	
Light	36.8 (41.2)
Moderate	43.4 (48.6)
Heavy	39.7 (44.5)

While daily gains of individual animals were lowest for heavy grazing, total gains per acre were highest for this intensity for the first 2 years of study. But this level of use proved the most detrimental to the forage. After 6 years, the gains for animals on the heavy use pastures declined to levels below those for animals grazed at light use. Forage production was seriously impaired by heavy use year after year and resulted in the least gains per acre by the end of the study. This situation was a primary factor leading to the original deterioration of western rangelands. Incorrect season of use was also a factor.

All systems of grazing resulted in sufficient gains for beef production when used at 65 percent. But, during the spring, grazing should be somewhat less than this level for lactating cows. Cows that calved on lightly grazed units entered summer ranges 30 lb (13.6 kg) heavier than cows calving on moderately grazed units, and 73 lb (33.1 kg) heavier than those on heavily grazed units.

Generally, daily weight gains by cattle were influenced by the quantity and quality of forage, which fluctuated with levels of precipitation. Peak gains were measured in years when rainfall was high and forage production was at its maximum. Conversely, animal gains declined when the amount of available forage was reduced. Lactating cows gained less throughout the study on the moderately grazed pastures as compared to the lightly

grazed pastures. All other classes of cattle gained as well on moderately grazed pastures as those lightly grazed. Average daily gains for five classes of cattle over all treatments were:

	Lb/day (kg/day)
Dry cows and steers	3.06 (3.43)
Pregnant cows	3.03 (3.40)
Lactating cows	2.49 (2.79)
Yearlings	2.47 (2.77)
Calves	1.77 (1.98)

Because cattle are generally fat after grazing on mountain ranges during the summer, and lower gains are expected on fall ranges, these researchers recommended that owners sell some livestock when they come off the summer ranges and use the crested wheatgrass pastures only for the breeding herd or stockers.

Forage yields.—During the 11-year study at Benmore, grass yields fluctuated with precipitation levels. However, differences in grass yields between the four systems of grazing were not statistically significant. Overall, grass yields were better maintained under the rotation and the delayed-10-days systems than under the other two.

Crested wheatgrass became dry during the hot summer months. Although western wheatgrass comprised only a minor amount of the total forage, it increased during the study period and was found to be a valuable complement to crested wheatgrass. Cattle grazed western wheatgrass in late spring after the crested had been well used. They also readily grazed it in the fall. Rhizomatous western wheatgrass also provided a much more uniform ground cover than crested and was superior for controlling soil erosion where it occurred.

Bulbous bluegrass also increased during the study, but it adversely affected crested wheatgrass production. Most bulbous bluegrass plants were within or close to crested wheatgrass crowns and used soil moisture earlier. In addition, bulbous bluegrass growth is short and dries early. The researchers noted that this species provided little forage for cattle under conditions at Benmore.

Frischknecht and Harris (1968) concluded that crested wheatgrass was an excellent source of livestock forage. It can furnish about 60 to 70 days of spring grazing and, with adequate early fall rains, 40 to 50 days of fall grazing, thus expanding the productive capacity of spring-fall ranges and easing the burden on limited summer ranges. Moreover, livestock will generally gain 40 to 50 lb of beef on each acre (44.8 to 56.0 kg/ha) of crested wheatgrass during the spring season if rotational grazing is practiced at about the 65 percent use level. These cattle then go onto summer ranges in excellent condition and the vigor of the forage is maintained.

An example of the value of green regrowth of crested wheatgrass for fall grazing in certain years was reported by Keck and Frischknecht (1968). Calves came off the mountain summer range with their mothers and remained with them on crested wheatgrass until they were sold 40 days later. During the time, the calves gained an average of 65 to 70 lb (29.4 to 31.7 kg) per head and some individual calves gained up to 90 lb (40.8 kg).

Nutrient Content and Palatability

After the 11-year pasture study the challenge was to find ways of integrating grazing of introduced grasses with native species, especially during the summer and fall. As plant growth advances, total protein in these grasses declines and amounts of cellulose and lignin increase (Cook and Stoddart 1961). Of the four introduced wheatgrasses tested, tall and intermediate wheatgrasses matured later and had lower levels of cellulose and lignin than did crested or pubescent wheatgrasses in midsummer. In fact, by the second or third week of June, the nutritive value of crested wheatgrass is below that required for lactating animals (Cook 1956). Therefore, researchers began to look at the native sagebrush-grass ranges as auxiliaries to grazing seeded pastures.

Cook and Harris (1952) reported that while cheatgrass is rather abundant, it remains green only a relatively short time and becomes unpalatable to livestock after maturity. Cook and Stoddart (1950) found that bulbous bluegrass and common winter rye (an annual) were also inadequate auxiliaries for range forage. Both species were uneconomical to establish and forage yields were much too low to be satisfactory. Planting perennial grass seed with common winter rye is also not recommended. Rye tends to compete with perennial grass seedlings for moisture and actually retards the final establishment of grass from 1 to 3 years (Benmore Field Day Report 1949, unpublished).

While healthy native sagebrush-grass ranges can be used satisfactorily from about May 1 to June 10, at other times they cease to meet the minimum nutrient requirements for lactating animals. Restoration of spring-fall ranges by seeding can meet a large part of these requirements. Cook (1966a) noted that approximately 35 lb (15.9 kg) air-dry herbage per day were necessary to sustain a cow and her calf. This amount includes forage lost by trampling, insect damage, rodents, and rabbits.[1] During early spring, cattle grazed on native sagebrush-grass ranges do less well than livestock on seeded ranges. Cows on the smaller Benmore pastures gained an average of 1.6 lb (0.7 kg) per day while cows on native ranges gained only 1 lb (0.4 kg) per day. Highest gains were made on intermediate and tall wheatgrass, both of which mature later than crested or pubescent wheatgrasses. Both intermediate and tall wheatgrass also meet the requirements of lactating animals better than the other two species because their protein and energy levels remain higher much longer

[1] Grasshoppers and rabbits, when numbers are at their peaks, do tremendous damage to grass plants, especially to new seedlings. Management provisions should be made to control their effects on stands. Research shows that only 20 grasshoppers per square yard on an acre (24 grasshoppers/m^2 on 0.4 ha) of range consume as much as a 1,000-lb (453.6-kg) steer (personal communications with Austin Haws, Utah State University. A series of exclosures on various wheatgrass stands show that both rabbits and livestock prefer intermediate wheatgrass to the other three species. On rabbit-fenced plots, an average of 796 lb per acre (892.2 kg/ha) were produced by all species. On unprotected areas, only about 531 lb per acre (595.2 kg/ha) were produced. Rabbits annually consumed about 33 percent of the forage—no minor consideration.

into the growing season. Crested and pubescent wheatgrasses also were lacking in phosphorus in the later season, but this deficiency was corrected by adding monosodium phosphate to the stock water.

When Cook grazed cows on pastures of Russian wildrye, he found that lactating cows did well. Livestock gained an average of 3.2 lb (1.4 kg) per day on this species, but only 2.8 lb (1.3 kg) per day on crested or pubescent wheatgrass. Yet, as already noted, Russian wildrye is difficult to establish and is not a heavy forage producer.

Once livestock were moved to mountain ranges, all livestock made similar gains regardless of previous treatment. However, native ranges may not provide sufficient nutrient levels, especially during lactation. Supplementation may be required. To answer one of the questions raised by Cook's study, Mitchell (1969) investigated the possible chemical differences in grasses at different times of the season. At first, Mitchell found no significant differences in the chemical composition of forage simultaneously collected in early spring from relatively pure, open stands of different grass species. But samples collected at different times during the grazing season showed apparent differences.

Russian wildrye, for example, had a total protein level that was higher than crested or intermediate wheatgrass during all collection times. However, crested wheatgrass was higher in protein in the early spring, but intermediate wheatgrass was higher later in the season. By July 1, Russian wildrye was lacking in phosphorus content, and Mitchell generally found that it responded to variations in climate much more radically than the other species. Even after maturity, Russian wildrye remains high in protein and can produce weight gains in livestock, usually until the seed shatters. Afterwards, animal weight losses may occur because digestible energy may be lacking.

Like Cook, Mitchell observed that although Russian wildrye had seeming advantages over the wheatgrass species, this species should not be solely relied upon because of its weightier disadvantages. Based on the Benmore experience, Cook (1966a) concluded that crested wheatgrass stands could be maintained indefinitely if not grazed at more than 55 to 60 percent use and if brush control were administered periodically. In addition, wolf plants could be adequately controlled by grazing every 3 or 4 weeks at a rate of 0.5 to 1.0 acre (0.2 to 0.4 ha) per cow for a few weeks in early spring after new growth has reached about 3 inches (7.6 cm). Excellent weight gains would thus result and the vigor of the grass stand maintained perpetually.

Because the numbers of cattle being permitted on high mountain ranges have been reduced in some areas, researchers began to look at whether crested wheatgrass pastures could be grazed all summer without producing harmful effects to livestock. Cook (1966a) and Vallentine (1959) concluded that pastures of seeded wheatgrass were far from adequate for season-long grazing. While animals could be rotated from one pure stand to another as the different species matured, the pastures were good only to midsummer and then livestock must be moved to summer ranges in the mountains. Research indicated that if the forage is inadequate nutritionally, cows rob their own bodies to feed the calves.

Protein Supplement in Summer

To investigate the feasibility of summer grazing on the Benmore crested wheatgrass pastures, Harris and others (1965) conducted a study between 1961 and 1963. Cows and calves were grazed during six consecutive periods from April 20 to December 15. Some cows received protein supplements of 0.75 lb (0.3 kg) per head per day (fig. 10).

Figure 10.—Cows at Benmore eat protein supplement from a wooden manger.

Researchers found that yearlings did not get as much of the supplement as older stock because they were pushed away. Still, yearlings made weight gains as the season progressed until early fall. Even after this date, losses were still slight. In the end, there were no significant differences in the final weights of the yearlings between the supplemented and the nonsupplemented treatments. Calves also showed no significant response to the supplement. Cows with the supplement finished the season 50 lb (22.7 kg) heavier than the nonsupplemented cows. Younger animals gained an average of 250 lb (113.4 kg) over the season. Moreover, gains of livestock grazed on forest lands during the summer did not differ markedly from gains of supplemented cows on Benmore pastures.

Therefore, where no alternative for summer and fall grazing exists, cows can be maintained with a supplement on crested wheatgrass and make gains comparable to livestock grazed on mountain ranges. In addition, a suitable feeder calf can be produced on such mature pastures. Yearlings, too, can make reasonable gains. These researchers concluded that when properly managed, crested wheatgrass will supply grazing from late April through mid-December.

A similar study reported by Harris and others (1968) reached many of the same conclusions. The study sought to determine if cattle grazing pure stands of crested wheatgrass at different seasons could gain weight either with or without a protein supplement. Yearlings and cow-calf pairs were distributed between a number of

pastures with the following treatments: early spring plus early fall grazing of crested wheatgrass, late spring, all spring, early summer, late summer, early fall, and late fall. For comparison, part of the animals were moved to an adjacent mountain range in the summer to assess gains on higher native ranges compared to gains on crested wheatgrass pastures. Fluctuations in yearly precipitation occurred during the 4 years of this study, resulting in variations in gains during the different grazing seasons. Nevertheless, some interesting findings resulted. Yearlings and calves showed no significant differences between the supplemented, nonsupplemented, or forest-grazed treatments. (Cows pushed yearlings away from the supplement, which may explain why the yearlings showed no response.) The calves gained consistently through all periods of grazing, averaging about 400 lb (181.4 kg) by the time they were sold, a gain of 250 lb (113 kg). The yearlings also finished the season with a gain in weight regardless of treatment, averaging 224 lb (102 kg) gain after losing slightly in the fall.

Cows responded positively to the supplement, ending the entire season with an average gain of 125 lb (57 kg) compared to only 50 lb (23 kg) for nonsupplemented cows. Furthermore, there were few significant differences in gains between cows grazed on mountain range in the summer and cows grazed on crested wheatgrass pastures with a protein supplement in the summer.

As expected, the highest gains per acre for all animals were in early spring and during the all-spring grazing treatments. But this study also demonstrated that livestock could be grazed from April to October on stands of crested wheatgrass and still make significant gains in weight. Hence, crested wheatgrass pastures may provide a viable alternative to higher summer ranges.

Integrating Crested Wheatgrass and Native Ranges

To further test grazing mature crested wheatgrass, Kearl and others (1971) experimented with the following grazing combinations involving 192 cows with calves:

1. Crested wheatgrass in the spring, summer, and fall. Summer grazing involved regrowth of crested wheatgrass in pastures grazed in early spring but rested in late spring.
2. Same as No. 1 except cows received supplement in summer and fall.
3. Crested wheatgrass in the spring, forest in the summer, and back to the crested wheatgrass in fall. Fall grazing involved mature growth of crested wheatgrass.
4. Same as No. 3 except cows received supplement in fall.
5. Crested wheatgrass in early spring, native range in late spring and fall, and forest range in the summer.

The purposes of this study were (1) to work out a viable system of grazing crested wheatgrass in conjunction with adjacent native range and higher summer range from mid-April to mid-December, and (2) to compare the merits of a protein supplement for cattle grazing on crested wheatgrass during the summer and fall when combined with spring grazing. Supplemented animals received the equivalent of 0.75 lb (0.34 kg) of supplement containing 35.6 percent protein and 2.3 percent phosphorus daily in three feedings per week. This study also compared biuret and cottonseed meal as protein supplements for cattle on crested wheatgrass.

Researchers found that cows all gained about the same during early and late spring, regardless of treatment (fig. 11). During summer little difference existed in gains between supplemented and nonsupplemented cows while grazing regrowth of crested wheatgrass that remained green into summer. Again, both of these groups also compared favorably with cows grazing forest ranges in summer. The biggest differences in weights between treatment groups occurred during the early and midfall, a period when mature crested wheatgrass is low in nutrients. All cows grazing crested wheatgrass showed losses in weight during the early fall, whereas those grazing adjacent native ranges gained weight during this period (fig. 11).

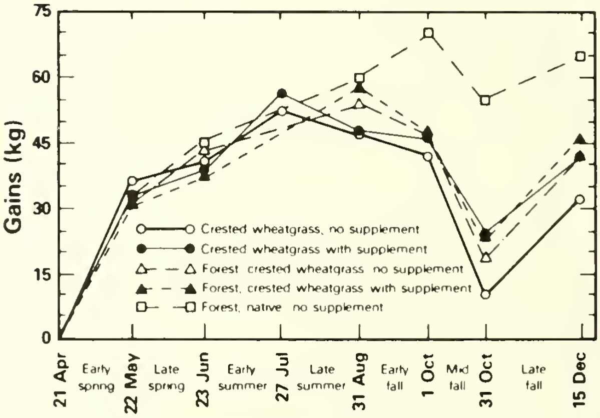


Figure 11.—Accumulative gains of cows on five grazing systems (see Kearl and others 1971).

The beneficial effects of the supplements were evident in early and midfall on crested wheatgrass not previously grazed in spring. These effects also carried over to the end of late fall (December 15) after all animals were grazed together on native range for 45 days without the supplement. In addition, cows that grazed crested wheatgrass season long but received supplement in summer and fall finished the entire season 22 lb (10 kg) heavier than similar cows that had not received the supplements. Cows supplemented on crested wheatgrass in the fall after grazing on forest lands in the summer finished the entire season 11 lb (5 kg) heavier than their nonsupplemented counterparts. Cows grazing the native ranges after coming off the forest mountain ranges finished the season 44 to 66 lb (20 to 30 kg) heavier than supplemented and nonsupplemented cows, respectively, grazing on crested wheatgrass for the entire period.

Calves also made excellent gains throughout the study. However, average daily gains were reduced slightly during midfall (October 31) when forage was dry and stemmy. Although none of the calves were supplemented, those on crested wheatgrass pastures all season long averaged 280 lb (127 kg) accumulative gains since late April, regardless of whether the mothers were supplemented or not. However, after coming off forest lands, calves on crested wheatgrass averaged 291 lb (132 kg) accumulative gain since going on pasture in late April. Calves on native grass pastures after coming off forest lands averaged 300 lb (136 kg) accumulative gain since April. Thus, calf gains followed somewhat those of the cows.

All differences in animal gains on crested wheatgrass in the fall were positive in favor of supplementation of some kind. Moreover, cattle gains tended to favor biuret over cottonseed meal. On the basis of this study, greatest gains in animal weight occurred with treatment No. 5 where cows and calves were grazed on crested wheatgrass in early spring, adjacent native range in late spring, forest mountain lands in the summer, and native foothill range again in fall. This combination appeared to be the most beneficial for both livestock and grass. Weight gains for these animals surpassed those supplemented on crested wheatgrass, yet the differences were small in some cases. Little difference was noted in gains between supplemented and nonsupplemented cows that grazed crested wheatgrass regrowth in the summer. Left still undetermined was whether these differences in cow weights among the five treatments at the end of the season carried over from year to year in breeding performance.

Frischknecht (1978b) concluded that improved native range, where the most prominent grasses are thickspike and bluebunch wheatgrasses, can be used for grazing in the late season in combination with crested wheatgrass pastures that are grazed in early spring. Depleted native range was improved by rest from grazing during the spring growing period, coupled with periodic sagebrush control. This combination restored these areas to a productive status equal to seeded crested wheatgrass range, which was 2.5 acres (1 ha) per AUM. Some rotation between seeded and native range is recommended so livestock do not graze the same range at the same time each year.

Sheep Grazing Studies

Studies were also conducted at Benmore to examine management of sheep on seeded spring-fall ranges. Because introduced grass species had proven so valuable for cattle, would sheep also benefit from seeded pastures? Cook and Stoddart (1961) reported that sheep tended to be more selective of various plant parts and ate more leafy material and avoided dry or coarse portions. Hence, intake declined as the grazing season progressed. Ewes, for example, gained weight in early spring but tended to lose weight in late spring on both crested and tall wheatgrasses. However, late season gains were reported for sheep on intermediate wheatgrass. Like cattle, sheep did not make good use of the less palatable pubescent wheatgrass.

In another study, Frischknecht and Harris (1973) grazed cattle in early spring and sheep in early and late fall on three 100-acre (40.5-ha) pastures of crested wheatgrass that had different densities of sagebrush. One goal was to determine if sheep could help maintain grass productivity by controlling the spread of sagebrush on seeded ranges. These researchers found that on pastures stocked uniformly at 40 to 50 sheep days per acre, depending upon the year, weight gains and losses of sheep in fall were directly related to the amount of sagebrush in each unit. For the lightest density—1.5 plants per 100 ft^2 (9.3 m^2)—sheep maintained their weight during the 5- to 6-week early fall season, but then lost an average of 3.5 lb (1.6 kg) per head in the 5- to 6-week late fall season. Where the density of the sagebrush was 3.5 plants per 100 ft^2, the sheep showed weight losses of 1.6 lb (0.7 kg) and 5.1 lb (2.3 kg) per head for the early and late fall periods, respectively. Greatest weight loss occurred on the pasture having 13 plants of sagebrush per 100 ft^2 (fig. 12), amounting to 3.5 lb (1.6 kg) per head in early fall plus an additional 8 lb (3.6 kg) per head in late fall. Overall, this study noted that sheep lose weight in cold weather and gain best when there is considerable green fall regrowth resulting from late summer and early fall storms.

In tests with cattle and sheep, Cook and Stoddart (1959) found that cattle made better use of seeded wheatgrass pastures than did sheep. Lactating cows continued to make gains throughout the spring season, while lactating ewes lost weight on some seeded species in the late spring season. This suggests that sheep may have to be supplemented or moved to summer ranges earlier purely for nutritional reasons. Cook also found that cattle could tolerate the summer heat longer than sheep on Benmore pastures, remaining on seeded pastures about 3 weeks later than sheep. However, ewes that grazed seeded pastures during spring produced about 20 lb (9.1 kg) more lamb at weaning than ewes that grazed the native sagebrush-grass pastures.

Figure 12.—Sheep lost weight when grazed on this range where sagebrush averaged 13 plants per 100 ft^2 (9.3 m^2).

COMPETITIVE RELATIONS BETWEEN GRASSES AND SHRUBS

On most ranges in the Intermountain West, pure stands of grass are infrequent except following fire. Brush species gradually invade seeded pastures even if no grazing has occurred. Researchers at Benmore, investigating the nature of competitive relations between grass and shrubs, have focused on rate and nature of brush invasion, growth characteristics, livestock preferences, and long-term trends.

Guidelines on Competition

One aspect of spring-fall ranges that has not been well understood is the competitive relationship between grasses and shrubs. Studies at Benmore have resulted in the following guidelines on this competition:

1. Brush species such as sagebrush and rabbitbrush compete with perennial grasses on western rangelands. Big sagebrush is a far more serious competitor with grass species than rubber rabbitbrush because of its lateral root system and growth cycle.
2. Taller brush species trap drifting snow, resulting in increased soil moisture in the immediate vicinity of brush plants.
3. Brush species can reinvade even the most vigorous foothill grass stands in certain years when moisture is above average regardless of whether or not grazing has been allowed. Periodic brush control will be required to maintain vigor of grass in competition with sagebrush.
4. To a limited extent, grass species can inhibit brush development, especially the roots if the grass plants are well established and vigorous.

Studies on Relations Between the Species

In the early years of their long-term grazing study on crested wheatgrass, Frischknecht and others (1953) recognized that big sagebrush and rubber rabbitbrush invaded most readily where there was less than a full stand of grass and in some heavily grazed spots. In the latter instances, young brush plants were commonly found in the dead centers or near the edge of severely weakened grass plants where the microenvironment was apparently most favorable. A few years passed before pastures as a whole showed increased brush invasion with increased intensity of grazing.

Frischknecht and Harris (1968) reported that sagebrush and rabbitbrush invaded most rapidly where grazing had been the heaviest. The invasion of these species into grass stands was also hastened by wet spring seasons following relatively dry years. In fact, both brush species have been found to invade so-called "slick" spots in wet years that are otherwise resistant to their invasion. Even so, because of the high concentration of salts in "slick" soils, the growth of these plants is slow, and they seem to be stunted and short-lived.

Cook (1966a) found that brush species will reinvade most seeded foothill ranges even if grazed only lightly. On sample plots, this researcher determined that 71 percent of the reinvading sagebrush was reestablished just 2 years after removal of the original stands. Big rabbitbrush reinvaded at a more moderate rate.

In a more detailed study, Cook and others (1967) noted that brush species—notably sagebrush and big rabbitbrush—invaded seeded pastures within the first 6 years after planting. The invasion of rabbitbrush was inversely related to grass density--good stands of grass restrict the rate of invasion. Sagebrush, however, tends to be more competitive and can invade more easily. For example, Cook and Stoddart (1951) reported that perennial grasses seeded into dense stands of sagebrush or cheatgrass rarely become established. Frischknecht (1978a) concurred with this finding, reporting that solid stands of sagebrush have developed on abandoned farmland and formed communities closed to grass seedling establishment. He also found (1962) that at Benmore young sagebrush plants invaded established stands of crested wheatgrass downwind from parent sagebrush plants. Ninety percent of sagebrush progeny were found within 30 ft (9 m) of parent plants (fig. 13). Some form of brush control is absolutely required to maintain grass productivity.

Figure 13.—Young sagebrush plants invade crested wheatgrass stands downwind of parent sagebrush. Rapid invasion occurs where parent plants are spaced about 30 ft (9 m) apart.

Frischknecht and Harris (1973) subsequently reported that, once established, sagebrush competes successfully with perennial grasses and in time tends to become dominant on spring-fall ranges. In years with above-normal spring precipitation, sagebrush seedlings were often able to invade even the most vigorous grass stands. Thereafter, these brush plants compete with grasses for moisture in the same rooting depths. In addition, sagebrush has the advantage of trapping snow around its base, which also improves its total soil moisture potential in the spring (fig. 14). Further, spring cattle grazing provides an additional competitive edge to sagebrush by weakening grass species at a time when the growth cycles of sagebrush and grasses coincide. Therefore, soil moisture not used by grass plants is made available

Figure 14.—Ungrazed grass plants as well as sagebrush and rabbitbrush cause snow to accumulate in drifts. This increases the soil moisture for these plants.

to sagebrush, which flourishes and gradually becomes more vigorous each year. Because the growth cycle of rabbitbrush begins later in the season, it probably does not inhibit the vigor of grass plants.

From a 3-year study of competitive relations on caged plots on grazed range, Frischknecht (1963) noted differences between rubber rabbitbrush and big sagebrush. Up to this time, researchers generally agreed that sagebrush provided stiff competition for grasses (Blaisdell 1949), but the documentation on rabbitbrush was less complete. In addition, more research was needed to determine why sagebrush was such a vigorous competitor with perennial grasses.

Frischknecht found that grasses and rabbitbrush appeared to carry on a mutually beneficial relationship. Crested wheatgrass grew more rapidly in the early spring underneath rabbitbrush plants. This grass was 4 to 6 inches (10 to 15 cm) taller than grasses in the open, but it was not preferred by cattle in the early spring even when the brush seemingly offered no real obstacle to grazing. However, crested wheatgrass under rabbitbrush plants remained more succulent and was subsequently favored by livestock in the fall. Even fall regrowth on crested wheatgrass plants under rabbitbrush was more lush than grass plants in the open or under sagebrush plants. Frischknecht concluded that the presence of rabbitbrush increased the value of grass for fall grazing (fig. 15).

With respect to sagebrush-grass relations, Frischknecht again found that spring grazing increased the competitive advantage of sagebrush (fig. 16). Conversely, crested wheatgrass appeared to have a competitive edge over rabbitbrush in both time of growth and type of root system. Crested wheatgrass seemed to inhibit the growth of rabbitbrush more so than rabbitbrush inhibited the growth of crested wheatgrass (also see McKell and Chilcote 1957).

A comparison of the root systems of both sagebrush and rabbitbrush by Frischknecht revealed that sagebrush

(A)

(B)

Figure 15.—(A) Crested wheatgrass shows high production under rabbitbrush prior to fall grazing. (B) The same location shows close use of grass under rabbitbrush after fall grazing by cattle.

Figure 16.—Barren areas tend to develop around sagebrush, in contrast to high production of grass under rabbitbrush.

not only had a taproot but highly developed lateral roots in the surface soils—that area where grass roots are also most numerous (fig. 17). Thus, they compete for the same soil moisture. Rabbitbrush, by contrast, tended to have a deeper taproot and less developed lateral roots. Considering the different growing cycles, time of season, and soil depth, soil moisture was used differentially by rabbitbrush and grass. Frischknecht therefore concluded there was little basis to justify control efforts on rubber rabbitbrush at Benmore, particularly where fall grazing was practiced.

During the early 1960's several researchers looked more closely at the competitive relations between these plants. Leonard (1964), for example, looked into competition for available soil moisture on Benmore's ungrazed areas. Soil moisture was significantly greater under rabbitbrush compared to crested wheatgrass plants during all test dates throughout the summer. These differences were more pronounced at 12 inches (30.5 cm) than at 18 inches (45.7 cm) deep.

However, Leonard found no significant differences in soil temperature between grass and brush. But soil moisture and soil temperature were found to be inversely related to time—the later the season, the higher the soil temperature and the lower the soil moisture.

Interestingly enough, on ungrazed range Leonard did find a significant decrease in air-dry herbage production for crested and tall wheatgrass because of the presence of rabbitbrush. These findings are somewhat different from Frischknecht's 1963 results on grazed range. Intermediate wheatgrass, however, seemed relatively unaffected by rabbitbrush plants. Cook and others (1965) pointed out that Frischknecht may have minimized, to too great a degree, the effects of rabbitbrush crown cover. These researchers reported that production was better for crested and tall wheatgrass plants within 36 inches (91.4 cm) of rabbitbrush plants compared to those within 10 inches (25.4 cm). These plants produced an average of 0.7 ounces (20 g) more forage, had a greater basal diameter, and produced more seed heads per plant. In addition, Cook and others (1965) reported that rabbitbrush used soil moisture more slowly than grass, but it still used moisture that would have otherwise been available to the grasses. They concluded that the grass growing underneath rabbitbrush plants appeared taller and more succulent because livestock merely grazed more accessible forage first. Only when most forage had been depleted, usually in the fall when good forage is scarce anyway, would cattle then graze grasses among the branches of rabbitbrush. These researchers said rabbitbrush was competing to the detriment of perennial grass species.

Leonard (1964) found additional evidence that rabbitbrush deters grass production. While no significant difference was noted in basal diameter in the presence or absence of rabbitbrush, the number of grass seed heads was significantly reduced, which was noted also by Frischknecht (1963). This latter difference was more pronounced for crested than for tall wheatgrass. Leaf length was apparently unaffected by the presence of rabbitbrush.

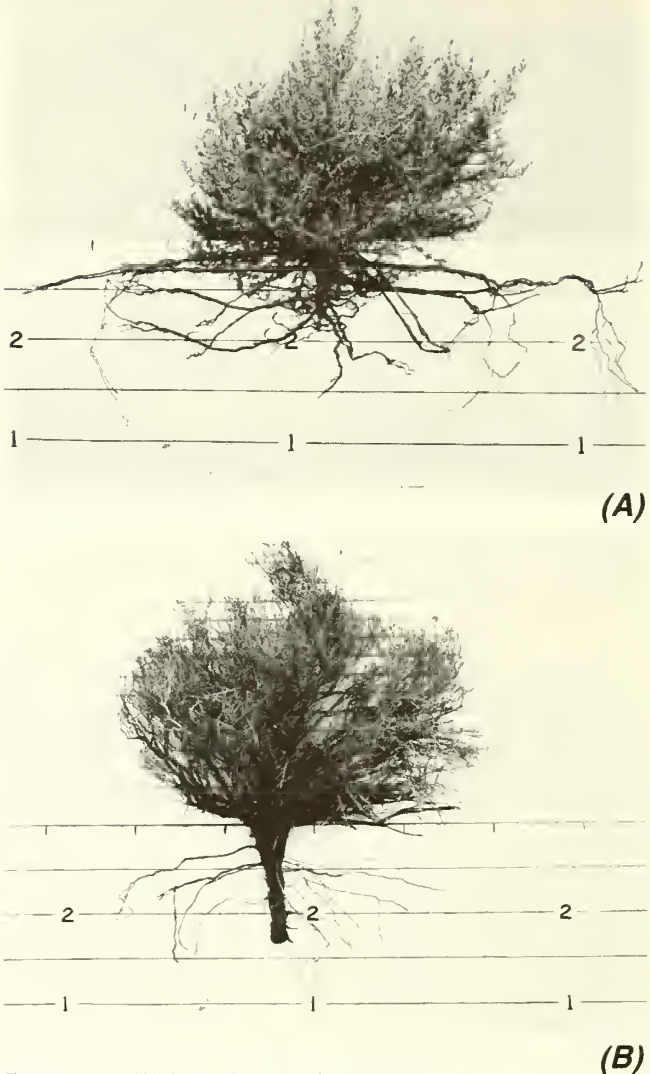


Figure 17.—(A) Lateral roots of big sagebrush provide keen competition to grass. (B) Rubber rabbitbrush growing near the same big sagebrush has prominent taproot, but lesser lateral root system.

Furthermore, Leonard noted that air-dry production was slightly greater for both crested and tall wheatgrass when growing in the absence of brush, nor did the grass apparently inhibit brush growth. Neither the height nor the base of brush species was affected by the presence or absence of wheatgrass plants. Yet, the presence of wheatgrass species did influence the development of lateral roots of brush—crested wheatgrass more so than tall wheatgrass. Leonard found fewer roots on the side of where wheatgrass plants were present. Root density was also less as a result of close wheatgrass plants. Still, root depth or penetration of the clay hardpan was unaffected by the presence or absence of wheatgrass plants.

Overall, crested wheatgrass appeared to use soil moisture much more rapidly and completely than did rabbitbrush.

CONTROLLING BRUSH REINVASION

As the preceding studies show, brush species such as sagebrush and rabbitbrush can easily reinvade improved rangelands regardless of the method of control or system of grazing. In fact, in certain years these species have reinvaded vigorous grass stands where all grazing was excluded. Big sagebrush competes with the grasses, and heavy infestations may ultimately reduce potential grass yields by as much as 70 percent.

Benmore studies show that moderate grazing coupled with an initial effective method of brush removal can reduce reinvasion. Nevertheless, periodic treatments for controlling sagebrush on improved ranges must be practiced to maintain grass yields and must be recognized by range managers as a maintenance cost.

Guidelines on Control

Several chemical and biological methods to control reinvading big sagebrush were studied at Benmore. The following guidelines resulted from those studies:

1. Under satisfactory conditions of temperature, humidity, and wind, adequate herbicide kills of sagebrush can be obtained from aircraft applications up to 200 ft (61 m) height of flight.
2. Rate of application of 2,4-D herbicide results in significant differences in rabbitbrush mortality, with 3- and 4-lb/acre (3.4- and 4.5- kg/ha) rates the most effective.
3. To successfully kill rabbitbrush, 2,4-D should be applied when soil moisture is above 13 percent in early June, particularly at the 2-ft (0.6-m) level.
4. The best herbicide kills of both big sagebrush and rubber rabbitbrush are obtained with mixtures of Tordon 22-K, Esteron, and Kuron.
5. Of livestock, sheep are the most effective control agents studied at Benmore. Cattle offer no hope of control of brush species.
6. Using insects for biological management of spring-fall ranges is impractical and unpredictable.

Chemical Methods

Total protection from grazing does not stop shrub invasions and plowing destroys both brush and grass alike. Therefore, a major area of investigation has been the use of chemical herbicides and defoliants to eliminate brush from improved ranges. One of the most common herbicides used on ranges has been 2,4-D.

In May 1958, Cooperrider and Worf (unpublished report) conducted a study on two sections (1,280 acres or 518 ha) of sagebrush range south of the Benmore crested wheatgrass pastures to determine the maximum height from which herbicides could be effectively applied from fixed-wing aircraft. The study sought answers to problems encountered by the Forest Service (Region 4) during the previous 10 years when chemical herbicides were first used as range improvement tools. Information to that time indicated that best results for control of big sagebrush were obtained from applications of herbicides flown 25 ft (7.6 m) or less above ground level. However, terrain and obstacles such as trees or telephone and power lines often made that height extremely hazardous for fixed-wing aircraft. Flights above this level also involved problems with herbicide drift and spotty applications.

Cooperrider and Worf designed a study to treat four large areas, each 0.5 by 1 mile (0.8 by 1.6 km) with a herbicide at the rate of 2 lb (0.9 kg) butyl ester in diesel oil at 3 gallons solution volume per acre (28.1 liters/ha). Heights of flight were 15, 50, 100, and 200 ft (4.6, 15.2, 30.5, and 61 m) above ground level using a World War II Navy Torpedo bomber flying at a constant groundspeed of 180 mi/h (289 km/h). An effort was made to apply the herbicide under uniform environmental conditions.

Cooperrider and Worf concluded that adequate kills of sagebrush could be obtained from fixed-wing aircraft flying 200 ft (61 m) above ground level if satisfactory conditions of temperature, humidity, and wind existed. They believed that weather factors were more critical than height of flight. Frischknecht (1978b) described the overall kill of sagebrush on this area and subsequent increase of new plants over a 12-year period (fig. 18).

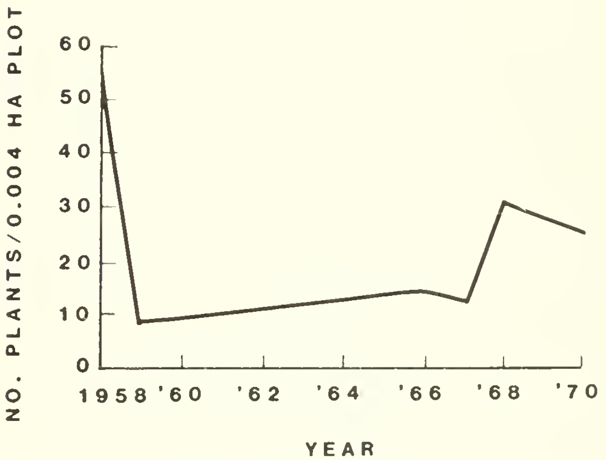


Figure 18.—Density of big sagebrush over a 10-year period following spraying in 1958.

In 1959, Cook and others (1965) treated 240 acres (97 ha) of big rabbitbrush on abandoned dry farmland. The initial treatment of 2,4-D Esteron 76E (50 percent isopropyl and 50 percent butylester) was applied at a rate of 3 lb/acre (3.4 kg/ha) in three replications. Portions of each plot were subsequently retreated in 1960, which gave five different treatments, including the unsprayed control. At the time of treatment, 70 percent of the rabbitbrush plants at Benmore were 7 to 8 years old, and the remainder were generally less than 5 years.

The rate of kill varied with the treatment and by date and year of application. For the initial treatment of 3 lb/acre (3.4 kg/ha), researchers found nearly an 80 percent reduction in foliage. This resulted in 56 percent greater mortality and a 48 percent greater reduction in foliage compared to unsprayed plots. The second application the following year increased the mortality by only an additional 18 percent.

There did not appear to be any appreciable differences in kill rates between application dates June 1 and June 15. However, the results changed from year to year. During 1960 and 1962 no significant differences were noted in mortality rates between the two application dates, but in 1961 the early date was more effective. Researchers could not provide an explanation for these differences.

The rate of application, however, resulted in significant differences in rabbitbrush mortality. In tests using 3- and 4-lb/acre (3.4- and 4.5-kg/ha) rates, over 80 percent of the rabbitbrush was killed and total foliage was reduced by 96 percent. The 2-lb/acre (2.2-kg/ha) rate killed 68 percent of the plants but immediately reduced foliage by 90 percent. Additional applications in 1961 revealed no significant increase in mortality rates.

Researchers monitored the treated areas for 3 years after the last application. The plants that were completely defoliated in the initial treatments were still dead, but those that suffered between 50 and 95 percent defoliation showed evidence of resprouting. Plants with 35 to 50 percent defoliation showed only superficial effects 3 years later. Thus, rabbitbrush can recover from almost total defoliation quite readily.

Because soil moisture is such an important component in successfully treating sagebrush with 2,4-D, researchers examined this variable at Benmore with respect to rabbitbrush. The best kills of rubber rabbitbrush were obtained on the June 1, 1962, application when soil moisture was 13.48 percent at the 1-ft (0.3-m) level and 13.86 percent at the 2-ft (0.6-m) level. The best kill for a mid-June date occurred when soil moisture in the upper 1 foot of ground was 10.24 percent but more than 13 percent at the 2-foot level. At these times, about 80 percent of the rabbitbrush plants were killed. In 1961, when soil moisture was only 11 percent at the two levels, the kill of big rabbitbrush was only 65 percent in early June and less than 50 percent in mid-June. Hence, to be successful, 2,4-D should be applied when soil moisture is above 13 percent in early June, particularly at the 2-ft (0.6-m) level. This area of soil may be most critical because of the taproot configuration of rabbitbrush roots.

Researchers also found that atmospheric temperatures were never critical for the successful application of herbicides on rabbitbrush at Benmore. Generally, the higher the temperature, the better the rate of kill. Overall, if daytime temperatures reached 70° F (21° C), and nighttime remained around 40° F (4.5° C), then soil moisture was the more limiting factor influencing the success of herbicide application (Bonham 1964).

These researchers concluded that a 3-lb/acre (3.4-kg/ha) rate application rate of 2,4-D is high enough in most cases to obtain satisfactory rates of kill for rabbitbrush if soil and weather conditions are favorable. Moreover, when rabbitbrush was controlled, grass yields increased an average of 336 lb/acre (376 kg/ha) two seasons after the herbicide treatments.

A study in the mid-1960's by Cook (1966b) examined the effects of different herbicides on sagebrush and rabbitbrush in Rush Valley. Because both species occur together in mixed stands, this study sought to determine which herbicide would efficiently kill both in one application.

Picloram (Tordon 22-K), an herbicide that was relatively new at the time, was used on both species. Esters of 2,4-D and 2,4,5-T (Kuron and Esteron 76-E) were also applied during the first week of June 1963. In 1964 and 1965 various mixtures of these three herbicides were applied on mixed stands, plus Tordon 101 (a mixture of 22-K and 2,4-D).

Results of this study have improved our knowledge about the relative effectiveness of herbicides for controlling brush. Esteron and Kuron gave excellent kills of sagebrush but were rather ineffective on rabbitbrush. Tordon 22-K and 101 did well on rabbitbrush but poorly on big sagebrush. The best kills on all locations were obtained with mixtures of Tordon 22-K, Esteron, and Kuron.

Biological Methods

In addition to mechanical and chemical methods of controlling brushy or woody species, studies at Benmore have investigated biological agents of brush control. A review of the subject was made by Frischknecht (1978a). Use of biological agents is a little known field, but one which demands more study.

Mechanical and chemical methods of control generally destroy the photosynthetic processes of plants and dissipate their chemical energy into the atmosphere. On the other hand, biological methods have the advantage of making this plant energy available to animals for conversion into protein that possibly can be used by people. Another important consideration is the role biological agents play in the range ecosystem. While much blame is placed on domestic livestock for causing deteriorated ranges, other biological factors also may be important. Three biological agents of brush control are livestock, insects, and, indirectly, nematodes. (Small mammals are discussed in the next section.)

Livestock as a biological control.—Frischknecht and Harris (1973) found that sheep are effective control agents on sagebrush ranges and reduce the need for costly chemical or mechanical treatments if grazing begins before sagebrush becomes too dense. As described earlier, when brush density was at or below 1.5 plants per 100 ft^2 (9.3 m^2), sheep exerted real controls on growth (fig. 19). In fact, this appears to be the only feasible density where sheep can act as a biological control. But even then, total plant numbers changed little during fall sheep grazing, although a few small plants were eliminated. The effect of sheep grazing was to decrease shrub size and production of seed. Moreover, these researchers found that once sheep grazing was discontinued after 6 years of treatment, sagebrush increased dramatically in both number and size of plants. And the greatest increases were in those plots where sheep grazing had reduced plant size most. Thus, sheep should be used every few years to effectively control sagebrush growth.

Kilpatrick (1965) found that a supplement of 4 ounces (0.1125 kg) protein per day encouraged sheep to use a greater percentage of sagebrush in their diets. Further,

Figure 19.—In area to right of the fence, sheep grazing in late fall greatly reduced the size of sagebrush and rabbitbrush. The area was also grazed by cattle in early spring. Area to left of fence was grazed only in early spring by cattle. Sagebrush density is higher than average in this area as a whole.

sheep can be herded closer together to induce heavier use of browse, and held on sagebrush ranges longer without harm to the vitality of the animals. Sheep owners confirm these findings.

Under the conditions at Benmore, cattle offered no hope of controlling brush species on seeded ranges—except indirectly by deferring spring grazing to let grass become more vigorous (Frischknecht and Harris 1973). Cattle ate only a few flower stalks in the fall—hardly sufficient for effective control. This was true even at the highest stocking densities. In other studies where cattle have been observed eating some sagebrush, it was either (1) because the cattle were overly concentrated and other forage was totally lacking, or (2) a more palatable variety of sagebrush was present than the type at Benmore.

Frischknecht (1978a) reported that defoliation of sagebrush is possible by animals or people brushing against the plant when leaves are frozen and brittle. This researcher selected 12 pairs of plants; one plant of each pair was defoliated by knocking the leaves off in January when the above environmental conditions existed. By early May, the leaf volume of these treated plants was found to constitute only about 5 percent of the untreated counterparts. But by the end of July, most of the defoliated plants had regrown nearly 50 percent of the leaf volume of untreated plants. There were fewer flower stalks produced on the defoliated plants, and 6 of the 12 treated plants produced no flower stalks whatsoever the year following treatment. Therefore, defoliating sagebrush plants by this method is inadequate for effective sagebrush control.

Insects as biological agents.—One population whose importance on the rangelands has not been sufficiently recognized is insects. This group is important because of its vast numbers, rapid dispersal, and rapacious appetites that should be expressed in AUM's. While some insects (predators) are beneficial to range management because they eat less desirable insects, others damage plants by killing localized cells or destroying seeds and fruit.

Some range managers advocate using insects as biological control agents on undesirable plant species, particularly sagebrush. What is needed is a species of insect that will infest such undesirable plants but not harm species that produce valuable forage for domestic and wild herbivores. For example, the sagebrush defoliator moth (*Aroga websteri*) infests sagebrush. Silken tunnels with fecal pellets woven into them harbor the larvae, which generally defoliate the apical sprouts. In 1962, this moth destroyed up to 15,000 acres (6 070 ha) of sagebrush in Oregon. Another 12 million acres (4,856,400 ha) of ranges were infested to some degree in 1963. Outbreaks of defoliator moths seemed to occur when predator insects failed to control high population buildups. Yet, means of controlling such outbreaks are not known (Frischknecht 1978a).

Another insect known to kill sagebrush is the leaf beetle (*Trirhabda pilosa*) observed in British Columbia in 1954 and 1955. A close relative (*Trirhabda attenuata*) killed over 2,000 acres (809 ha) of sagebrush near Thermopolis, Wyo. For some reason, though, these species do not affect sagebrush plants near anthills.

Thrips are insects that obtain food by sucking out the contents of plant cells, destroying their photosynthetic capabilities. By 1949, scientists had identified 47 species of thrips in Utah, and most were found in sagebrush-grass ranges. Hence, thrips deserve closer attention to help determine their role in the range ecosystem.

Tingey and others (1972) studied thrips and their effects on four plant species at Benmore: sagebrush, rabbitbrush, antelope bitterbrush, and crested wheatgrass. These researchers hoped to discover whether this variety of insect could be useful to resource management goals.

Collections of 20 species of thrips were made during the summers of 1966 and 1967 on a variety of sites at Benmore. Only eight species were found in any significant numbers. Nine species were found only on one plant type, while only one species of thrips occurred on all four plant types. Crested wheatgrass had the most diverse collection of thrips, and antelope bitterbrush the least.

One species (*Anaphothrip zeae*) was the most abundant in July and was one of the 12 varieties found on crested wheatgrass. This species generally inhabits grass and sod, and can cause considerable damage to grains and grasses when it occurs in high densities. During this study, however, their numbers were small and thus their damage potential was thought to be limited.

A second species of thrips (*Aptinothrips rufus*) was also collected frequently from crested wheatgrass plants. This species also prefers wheatgrass species in Europe. Although populations could rise high enough to cause considerable damage to plants, they were not found sufficient at Benmore to cause concern.

A third thrips (*Frankliniella occidentalis*) was collected frequently on rabbitbrush in July. It is known to cause considerable damage through feeding on plants

and at times may transmit plant viruses. This variety of thrips reportedly (Ferguson 1963) infests bitterbrush and could negatively affect this valuable deer forage as well as the less desirable rabbitbrush.

Other insect studies.—In addition to thrips, other insects were collected from the four plant species mentioned earlier in a cooperative study between the Intermountain Forest and Range Experiment Station and Brigham Young University. Researchers note the kinds of damage inflicted on plants, but in many cases the extent or quantity of damage was not easily accessible (Jorgensen and Tingey, unpublished report).

In certain locations, spittlebugs were numerous on both big sagebrush and rubber rabbitbrush. Of the two main subspecies of rabbitbrush, the bright green variety was the preferred host over the white-stemmed subspecies. Spittlebugs by themselves seem to have little overall effect on plant vigor, but the quantity of dying and necrotic tissue left after feeding was impressive. The spittle appeared to have a digestive effect on the stem and leaf epidermis, resulting in a noticeably light brown to tan discoloration where insects had fed.

Larvae of the defoliator moth were usually found in most sagebrush stands, although not in sufficient numbers to produce significant damage in the Benmore area during the period of this study. However, sagebrush has been killed during periods of severe outbreaks of this insect in the Benmore area and in northwest Utah.

Jorgensen and Tingey (unpublished report) found many species of aphids on big sagebrush, but the extent of damage to the plant was again difficult to assess. Other insects found on sagebrush include various weevils, lepidopterous insects, and various gall insects. Interestingly, Frischknecht and Baker (1972) reported that a preponderance of the big sagebrush plants killed by meadow voles were those that also showed insect damage in the form of galls.

Cicada nymphs were often abundant on the roots of rabbitbrush. Their presence and relative abundance can usually be determined in midsummer by examining the soil around the bases of individual plants for emergence holes. Cast skins, which usually occur on the lower branches of shrubs adjacent to the emergence holes, can also be used as an index of relative abundance.

Apparently several generations were represented in various sizes of nymphs. Nymphs were usually found from 12 to 36 inches (30.5 to 91.4 cm) below the surface where they live in tunnels that are exposed to a root. Most nymphs were found in the lateral root system rather than on the tap root. Although most infested plants appeared unharmed by their presence, in times of water shortage plant production may be limited by their presence. Adult females often cause considerable damage by ovipositing eggs just under the cambium in the terminal stems, but this type of damage was not observed on rabbitbrush during this study. The fact that nymphs were found underneath these plants would suggest that they originated from eggs deposited in the stems, and upon hatching dropped to the ground and burrowed into the soil.

Both sagebrush and rabbitbrush are particularly susceptible to gall insects. At least three types of galls were found in the Benmore area. Little is known about the effects of galls on plants. Research shows that they are malformations of the host plants caused by insects that lay their eggs in the plant tissues, which then swell when the eggs start to hatch. Galls appear to be host-specific and differ widely. A study in Utah by McArthur and others (1979) showed that "cotton" galls were most frequently found on specific subspecies of rubber rabbitbrush, notably threadleaf and green rubber rabbitbrush, whereas "callus" galls were found almost exclusively on white rubber rabbitbrush. A type of gall called "mace" was found on all three of the above subspecies of rabbitbrush, but it was the only type of gall found on mountain rubber rabbitbrush.

Jorgensen and Tingey (unpublished report) found that rabbitbrush harbors several species of lepidopterous defoliators. One forms a tunnel by cementing three to six leaves together, and then feeds within the enclosed area. The others generally feed within a protective silk case. No species appears to cause substantial damage. Also, a small chrysomelid beetle causes noticeable damage on rabbitbrush in local areas. These insects feed upon the leaves as adults and in many cases destroy the epidermal tissue.

In the Benmore area, most rabbitbrush plants showed some borer activity, generally in the gnarled portion near the base of the plant. Many old galleries and some new galleries with early instar larvae were found, but few adults or pupae. Most of those collected were weevils, although other families were occasionally observed.

Knowlton (1966) reported that larvae of a weevil killed more than 15 acres (6.1 ha) of rubber rabbitbrush in southcentral Utah. Plant crowns and roots were riddled with tunnels. Mold often followed the insect injury into the below-ground galleries. Smaller tunnels were present in some aboveground stems. Larvae, pupae, and adult weevils were present during late August 1960. Insect numbers were even higher in similar root tunnels of apparently healthy rabbitbrush located around the edges of the dead and dying areas. Dead, moldy adult weevils were fairly common in drying rabbitbrush tunnels and not common in healthy looking plants. Similar damage to rabbitbrush has been noted in other areas.

When the insect study was conducted at Benmore, the blackgrass bug was not found. However, in other parts of the State it had caused heavy damage to crested wheatgrass and other introduced grasses as well as to the native Great Basin wildrye. Researchers have found that grass monocultures are more susceptible to damage by blackgrass bugs than where shrubs such as sagebrush and rabbitbrush occur.

Nematodes.—A cooperative study between the Intermountain Forest and Range Experiment Station and the University of Utah was conducted to determine the effects of plant parasitic nematodes on crested wheatgrass (Havertz 1957). This study was conducted both in the field at Benmore and in the University of Utah greenhouse.

The greenhouse experiments were divided into two parts: (1) 20 clay pots were filled with soil from Benmore—10 of the pots contained nematode-infested soil

and 10 contained soil that had been fumigated with ethylene dibromide; (2) 24 clay pots were filled with soil from Benmore—12 contained nematode-infested soil and 12 contained soil that had been sterilized with steam. In each case, crested wheatgrass seeds were planted in the pots. Subsequently, 467 crested wheatgrass seedlings grown in the greenhouse were processed to compare their growth in treated and untreated pots.

The following conclusions were drawn from the greenhouse study:

1. Crested wheatgrass plants grown in soil that had been fumigated with ethylene dibromide had an average of 26 percent longer top growth than those grown in nematode-infested soil.

2. Crested wheatgrass grown in soil that had been autoclaved had 24 percent more top foliage and 55 percent more root growth than plants grown in nematode-infested soil.

3. Every soil sample obtained from Benmore contained several species of nematodes; among them plant parasitic species (*Tylenchorynchus dubius* and *Tylenchus davainii*).

4. The root tissues of crested wheatgrass were inhabited by many nematodes of a species (*Nothotylenchus acris*) considered endoparasitic by Havertz.

The study at Benmore was conducted in two experimental plots. A plowed and harrowed plot in each of two pastures measured 66 by 66 ft (20.1 by 20.1 m) in dimension. These large plots were divided into quarters; opposite quarters were fumigated with ethylene dibromide, and the other two quarters were left untreated. The plowed areas in both pastures were then seeded with crested wheatgrass. In one pasture, crested wheatgrass grown in soil fumigated with ethylene dibromide produced an average of 16 percent heavier growth than that grown in nematode-infested soil. However, in the other pasture, crested wheatgrass grown in soil similarly fumigated produced generally less growth than the plants grown in nematode-infested soil. This anomaly was attributed to the high moisture content of the soil, which prevented proper aeration after fumigation; the seedlings displayed evidence of phytotoxicity.

This study, both in the greenhouse and in the field, led to the conclusion that plant parasitic nematodes may contribute to the decline of crested wheatgrass yields in the Benmore area. More field experimentation, however, should be carried out under more rigidly controlled conditions and for longer periods.

WILDLIFE HABITAT and BRUSH CONTROL

The Benmore Experimental Range was used to examine how small mammals and nongame birds are affected by control of vegetation. This is an area of increasing interest to wildlife managers. Attempts have been made to study occurrence and number of species, and the response of species and populations to range treatments.

Guidelines on Wildlife Habitat

Small mammals and nongame birds at Benmore have been the subjects of studies on their role in range ecosystems. The following guidelines have been gleaned from those studies:

1. Seeding programs increase pocket and harvest mice numbers where subsequent grazing by cattle is light, and increase deer mice populations where use of forage is heavy.

2. The highest incidence of big sagebrush kill by cyclic eruption of vole populations occurs in draws and low places that have a dense cover of grass and snow accumulation.

3. The summed data for small mammals reveal no differences between four plant control treatments 4 years after application.

4. High plant species diversity and good plant cover appear to enhance rodent populations.

5. Removal of trees will favor increases in grassland-savanna species of birds at the expense of woodland species. However, 1 year after tree removal, numbers and biomass of birds increase and then exceed pretreatment levels.

6. Of three methods of sagebrush removal tested, burning appeared to have the greatest impact on bird populations. Spraying, on the other hand, leaves suitable habitat for some species for a number of years. Chaining appeared to have the least detrimental effect on sagebrush-dependent bird species.

7. Range improvements should be conducted either in the early spring or late summer/early fall to minimize deleterious effect on bird habitat. In addition, large blocks of land should not be treated; rather, strips of vegetation should be left to provide cover and food for the resident avian species.

Small Mammals

Some interest has been focused on small mammals and their role in range ecosystems. A study by Black and Frischknecht (1971) at Benmore sought to determine the kinds of small mammals present on the pastures and their role in the range ecosystem. Traps were set at sample sites and yielded 587 rodents over 2 years. Three species comprised over 98 percent of the catch: deer mice (65.5 percent), western harvest mice (19 percent), and Great Basin pocket mice (14.3 percent). Deer mice were most prevalent on the heavily grazed units. On sites that had not been grazed or plowed, deer mice were the most abundant in units of relatively short cover containing only native plants. Harvest mice were more prevalent on the moderately grazed sites, most abundantly in units of tall cover of mixed native and introduced species. Pocket mice were most abundant in nongrazed areas with a mixture of native and seeded grasses and where grass cover was heavier than on any other site.

Studies have shown that some insects increase where grazing is heavy. Because insect larvae is the most important food for deer mice in summer and fall, this may explain why the mice were abundant in heavily grazed areas and areas with the least amount of cover.

Seeds are the most important food in the diet of harvest and pocket mice. Hence the mice are generally found in sites with heavy ground cover. Harvest mice were notably rare in nongrazed native grasses that tended to be shorter than adjacent introduced grass stands.

Black and Frischknecht (1971) suggest that seeding programs increase pocket and harvest mice numbers where subsequent grazing by cattle is light. In contrast, seeding programs increase deer mice populations where use of forage is heavy. There was no correlation evident between the relative abundance of any rodent and species of grass.

Voles kill and damage sagebrush and other shrub species by girdling the stems and branches. In winter 1968, voles killed and damaged big sagebrush over sizable areas of Utah and Nevada. Similar reports came from southern Idaho and Montana. Thus Frischknecht and Baker (1972) conducted a study to assess the possibility of taking advantage of peak vole populations to improve ranges infested with big sagebrush. Eight sampling areas near Benmore were selected to determine the amount of brush killed and the species of vole present. All sample areas were located above 6,500 ft (1 980 m) because little vole damage was noted below this elevation. Average annual precipitation on the study sites ranged between 15 and 20 inches (38 and 51 cm), of which 60 percent fell as snow. Five of the study areas were in drainages where snow lasted all of winter.

The species of vole responsible for girdling was determined by one night's trapping with two snap traps placed on each of 80 plots. During the equivalent of 160 trap nights, 23 long-tailed voles and 20 deer mice were captured. The deer mice were uniformly distributed, but the voles were caught more at the plots in higher elevations. The trappings followed the incidence of heavy brush kill.

The researchers found that some sagebrush stems were girdled to the level of the snow—up to 20 inches (51 cm) in some areas.

Overall 59 percent of the big sagebrush plants on the sample plots were killed completely by voles and 28 percent showed some damage. The highest incidence of kill was observed in draws and low places that had a dense cover of grass and snow accumulation. This finding supports observations by Mueggler (1967), who noted that the greatest sagebrush kill by voles in Montana occurred in protected spots where snow accumulation was continuous. Apparently a good herbaceous cover is conducive to the buildup of high vole numbers because they can form runways through the accumulated litter and thus escape predation. Another important factor appears to be persistent snow cover.

Of real significance in the study by Frischknecht and Baker were two areas left ungrazed by livestock during 1968. On these areas, the voles killed most of the sagebrush the following winter, boosting the yields of the herbaceous species. Some girdling was also observed on rubber rabbitbrush and yellowbrush, the former only in canyon bottoms, the latter everywhere. Up to 50 percent of the rabbitbrush plants were killed completely, and most of those surviving showed some damage. Few of the yellow brush plants were killed. About one-half showed no damage at all. No damage at all was observed on herbaceous species.

Knowing the requirements for good vole habitat, ungrazed shrub-grassland communities conceivably might have been influenced by voles over the years prior to settlement. Microtine populations are known to be cyclic, but they are difficult to predict. Some researchers observed a 4-year cycle in vole populations. A better understanding of the factor or factors that trigger eruptions in such rodent populations would be highly valuable.

Baker and Frischknecht (1973) focused on the impact of small mammals on renovated rangelands where pinyon and juniper had been removed. Six areas were studied, most near Benmore. Four treatments of pinyon-juniper rangeland were sampled: (1) untreated, old stands with little understory; (2) chained two ways and seeded; (3) chained, windrowed, and seeded; and (4) chained, windrowed, seeded, and burned. The equivalent of 7,350 trap nights produced 1,321 small mammals of 13 species:

Species	Percent of total
Deer mice	83
Great Basin pocket mice	7
Long-tailed voles	2.8
Western harvest mice	2.1
Chisel-toothed kangaroo rats	2.0
Total	96.9

Initially, clearing reduced rodent populations. In the second year after treatment there was a dramatic increase in the catch of deer mice and pocket mice, except on the untreated areas. In the third and fourth years after treatment, the catch dropped to a lower level but remained higher than before treatment. Some preference was indicated in individual years for heavier cover in some, but not all, situations. In the second year, some preference was shown for slash cover, especially windrows. Voles showed a strong preference for heavy cover; thus, piling trees creates vole habitat. The few pocket mice caught showed no differences between treatments.

Apparently, a high degree of edge afforded by the narrow strips of different treatments at Benmore created a generally favorable habitat for small mammals in comparison to other areas where second-year catches were not as large as at Benmore. Four years following treatment, the summed data for small mammals revealed no differences due to treatment. These findings were further substantiated by Baker (unpublished report) in other trapping studies.

A more recent rodent population study reported by Nichols (1972) and Nichols and others (1975) examined sagebrush communities representing three elevational gradients near Benmore: 5,100 ft (1 554 m), 5,700 ft (1 737 m), and 6,500 ft (1 980 m). The three areas were live-trapped simultaneously for six trapping periods. These catches were toe-clipped for identification, and species, sex, age, weight, trapping station, and general condition of the rodent were recorded. At the end of

the six trapping periods, each area was "kill-trapped" for comparison with the previous live-trapping periods.

This study indicated that the lowest elevation areas had a higher population total early in the summer followed by a decline and eventual leveling off in the fall. The intermediate elevation area showed three separate population peaks with the highest peak coming in late summer, around the middle of August. The highest elevation area showed a gradual increase in rodent numbers that also peaked about the middle of August and then declined by early September.

Western harvest mice were found only at the lower elevation sites and Great Basin pocket mice only at the highest elevations. In all three gradients, the most common species were deer mice and the least chipmunks.

This study revealed that the highest area had the most diverse rodent presence and was also the most stable in terms of the annual cycle for rodent populations. Plant species diversity was also the greatest on this site. Whether there is a relationship between the presence of rodents and the presence of sagebrush was not addressed by these researchers. However, high plant species diversity and good plant cover appear to encourage increased rodent populations at the elevations studied.

Nongame Birds

The Benmore Range has been used in recent years to examine the effects on small mammals and nongame birds of manipulating vegetation areas of increasing interest to wildlife managers. Baker (unpublished report) investigated nongame bird responses to pinyon-juniper removal and range seeding. One study area had been treated by chaining and windrowing of trees and seeding forage species—introduced wheatgrasses, alfalfa, and sweetclover.

Baker found that number of individuals, number of species, and biomass of birds declined markedly the first year following tree removal. But the next year, the second growing season for the seeded forage species, numbers and biomass increased dramatically and exceeded the pretreatment level. Species of grassland birds, principally meadowlarks, vesper sparrows, lark sparrows, horned larks, and common ravens, accounted for most of this increase.

Other bird species were negatively affected by tree removal at Benmore. The plain titmouse, usually considered to be an obligate of pygmy conifers, was one of the more common birds before treatment, but disappeared after treatment. Tree removal also decreased the numbers of gray flycatchers observed on the treated area. Other species negatively impacted by removal of the trees were the scrub jay, the chipping sparrow, and the common bushtit.

Finally, Baker noted that a number of bird species exhibited variable responses to tree removal. Brewer's sparrows, for example, declined immediately after treatment but returned to their pretreatment levels in 1 year. Similar responses were noted for housefinches and mountain bluebirds. Grassland birds continued to be important on treate' areas for at least 7 years following treatment.

A second study conducted by Castrale (1981) investigated the effects of controlling sagebrush on nongame birds. Three 40-acre (16-ha) study sites were selected near the Benmore area. One site where sagebrush had reinvaded since treatment in 1963 was designated as the control. Of the two sites recently manipulated, one was chained and seeded to grasses and the other was burned after having been previously seeded.

Castrale found that total nongame bird densities and numbers of species were similar on all three sites. However, densities of certain species differed between sites. Brewer's sparrows and sage thrashers, for example, decreased markedly on the treated sites and thus have been termed sagebrush obligates. Castrale found that burning more severely affected their numbers than did chaining. In fact, if the burned site had lacked patches of sagebrush missed by the burn, Brewer's sparrows would probably have been absent entirely as a breeding bird.

For the most part, densities of vesper sparrows and western meadowlarks were not noticeably different between control and burned sites. Vesper sparrows were essentially absent from the chained site, which is difficult to explain. Western meadowlarks, considered to be a true grassland bird species, showed slightly higher densities on treated areas.

The horned lark was the only species to show decidedly higher densities on sites subjected to sagebrush control. Widespread in distribution, horned larks are most common in disturbed grassland habitats, and the treated sites contained more bare ground and less litter cover than did the control. Horned larks selected open areas on all sites and were occasionally seen perching at the edges of sagebrush islands.

Differences in bird populations among sites may also have been due to the effects of sagebrush removal on the food base. Spring and summer food habits range from totally insectivorous for sage thrashers, through highly insectivorous for Brewer's sparrows and western meadowlarks, to predominantly granivorous for vesper sparrows and horned larks. Biomass and composition of insect communities would be affected by changes in the biomass and species composition of plant communities. These changes would alter the availability of preferred and required foods, causing changes in the suitability of sites that may be reflected by differences in bird densities.

These findings from Castrale's study are consistent with bird responses reported for sagebrush control by spraying except that burning caused more immediate and persistent reductions in sagebrush habitat. Effective spraying of shrubs continues to offer cover and suitable nest sites for shrub-dependent birds (such as Brewer's sparrows) for several years after treatment. On the other hand, effective burning consumes whole shrubs, and the effects on bird populations are immediate. Chaining has the least detrimental effect on sagebrush-dependent birds.

Castrale concluded that management objectives for sagebrush bird communities should be to provide sufficient habitat compatible with other uses for maximum diversity and density of birds. To effectively provide

these habitats, Castrale recommended that areas should be chained, burned, or sprayed in strips of 328.1 ft (100 m) wide rather than in large blocks. Untreated strips should be 328.1 to 656.2 ft (100 to 200 m) wide to provide sufficient areas for sage thasher populations. In addition, sagebrush areas should be treated prior to territory establishment by birds in the early spring or after birds have left the area in late summer or early fall. In all areas, scattered shrubs are desirable because they are frequently used as perches by all bird species.

NOXIOUS WEEDS

A problem with reseeded and overgrazed rangelands in the Great Basin area has been the proliferation of noxious weeds, most of which are introduced and some of which are poisonous. Cheatgrass, halogeton, Russian thistle, clasping pepperweed, and bur buttercup have all become problems. All these species tend to invade disturbed or poor condition areas, and all have become established components of range ecosystems, requiring special management techniques.

Guidelines on Noxious Weeds

Several studies at Benmore on dangerous and non-nutritive weeds have resulted in the following management guidelines:

1. The intensity of grazing strongly affects the rate of invasion of halogeton into stands of crested wheatgrass: the heavier the grazing, the more likely halogeton is to appear.

2. Halogeton begins to decline on pastures where spring grazing is discontinued and switched to summer or fall grazing. At least 2 years of deferment is necessary to decrease frequency.

3. Halogeton occurrence favors disturbed areas; abundance depends on year-to-year precipitation.

4. A number of control methods, including successful reseeding of depleted areas with perennial grasses, will slow the advance of halogeton.

5. The best insurance against invasion by halogeton is a vigorous stand of perennial range plants and variations in grazing.

6. The density of bur buttercup appears to be related to number of species present and frequency of introduced species. It is more abundant in heavily grazed pastures and has a close positive association with other annual weeds.

7. Bur buttercup has no forage value for livestock. While the weed should not be enhanced, total elimination is impractical. Control of bur buttercup by herbicides is possible where valuable perennial species would not also be killed.

Halogeton

Halogeton was first discovered in 1934 near Wells, Nev. Related to Russian thistle, it is an introduced annual from Asia that has spread over vast areas of the salt deserts in the American West. Found in only eight Western States in 1957, halogeton has since spread to 10 more States and continues to advance. So far, control measures have not been successful. In 1942 near Wells, 100 sheep died after eating halogeton on what was previously good livestock range. Before these deaths, many sheep owners thought halogeton to be a good source of forage. But it contains high levels of oxalic acid, a highly toxic element. As late as 1971 in southwestern Utah, 1,300 head of sheep died in one night from eating halogeton.

Halogeton was first observed on pastures at Benmore in 1952 (Frischknecht 1967, 1968a). By 1957 it had spread to 22 of the 28 100-acre (40.5-ha) pastures. Scientists believed that the seeds of this plant probably entered Rush Valley from the west in the late 1940's, perhaps carried along roadways or stock driveways. First observed on "slick" spots in Benmore's most northern pastures, consideration was initially given to eradicating the plant. However, researchers decided to study halogeton to learn more about its physical and chemical characteristics.

At the time of its original invasion, the grass stands at Benmore were 10 to 14 years old and well established. Researchers plotted the distribution of halogeton each year between 1952 and 1958 during early September when it was most easily recognizable. The soils supporting halogeton and those without were analyzed, precipitation recorded, and photographs taken.

Frischknecht found that intensity of grazing strongly affected the rate of invasion of halogeton into stands of crested wheatgrass—the heavier the grazing, the more likely halogeton was to appear (fig. 20). By 1956, the heavily grazed units had 83 percent of all the halogeton plants, compared to only 15 percent in moderately grazed units, and 2 percent in the lightly grazed pastures. In the latter two cases, halogeton was generally confined to the spots where livestock grazed heavily. In 1961, halogeton began to decline on pastures where spring grazing was discontinued and switched to summer or fall grazing. By 1964, halogeton was found only on units where spring grazing was still continued. Frischknecht found that at least 2 years of deferment from heavy spring grazing were necessary to decrease the frequency of halogeton on seeded rangelands.

Frischknecht concluded that, because the plants moved from north to south at Benmore, the halogeton seeds were probably spread by intermittent winds, animals, and vehicles. He also believed that the spread of halogeton was directly related to topography and soils. Most halogeton plants occurred on ridges that had experienced sheet erosion and loss of topsoil. Soil moisture was also lower on these areas than in surrounding areas. These soils had a higher salt content, which made these areas unfavorable to the growth of perennial grasses but which was especially favored by halogeton. Evidence also suggested that the presence of alkali bees in an area may be an indicator of favorable conditions for halogeton. The same conditions required for bee nesting apply to the establishment of this noxious annual.

Halogeton also appeared to favor disturbed areas where other species offered little competition. Roadsides, rodent workings, gravel pits, borrow pits, airstrips, and areas around stock watering tanks are likely places for halogeton to invade.

(A)

(B)

Figure 20.—(A) Halogeton grows profusely on a heavily grazed unit. (B) The weed is confined to heavily grazed spot in lightly grazed range.

The abundance of halogeton was also found to be dependent on year-to-year precipitation. Because halogeton seeds can persist for up to 10 years before germinating, outbreaks can fluctuate with rainfall. At Benmore, the greatest increase occurred after higher than normal July through September precipitation in 1954 followed by above average May to June precipitation in 1955.

Fischknecht (1968a) reported a number of control methods, such as successful reseeding of depleted areas with perennial grasses, will slow its advance. In addition, patches of halogeton can be mowed, bladed, sprayed, or grubbed, but at some expense. Applications of 2,4-D at a rate of 1.25 lb per 5 gallons (0.6 kg/18.9 liters), of water for example, have been effective in killing nearly 100 percent of the existing halogeton in the spring. But the seeds of past years maintain the stand if perennial grasses are not immediately established. Applications of Tuperson (a Dupont product whose common name is Siduron and is urea based) often kill even the halogeton seeds.

Because similar conditions to those at Benmore exist elsewhere, it appears that halogeton has not spread to its full range of adaptability. The best insurance against the invasion of halogeton is a vigorous stand of perennial range plants; variations in grazing, particularly occasional deferment during the growing season, helps keep these stands vigorous.

Bur Buttercup

Bur buttercup, a native plant of southeastern Europe, is a low-growing, highly adaptable winter annual that has spread rapidly since first collected in America in 1932 near Salt Lake City. As with many highly adapted introduced weeds, by the time it was recognized as undesirable it had gained such a foothold as to make total control impractical.

By the mid-1960's, the species appeared to occupy vast areas that once supported cheatgrass; some stockowners indicated they were unable to get stands of common rye started on areas where bur buttercup had invaded. The species also appeared to be well adapted to "alkali" spots that support heavy stands of halogeton in the late summer and fall.Apparently, seeds are dispersed by water, livestock, and other animals as well as by people and vehicles. By 1965 the species was observed in the crested wheatgrass pastures at Benmore. Because of its rapid spread and potential as a weed, a cooperative agreement between the Forest Service and the University of Utah was initiated in 1966 to study its life history, ecology, and distribution.

Buchanan (1969) noted that a scarcity of species, together with a high frequency of introduced species, might identify areas especially prone to invasion by bur buttercup. Density of bur buttercup was highest in the low frequency halogeton communities that also had a high frequency of introduced species. Although greasewood and shadscale communities had relatively high frequencies of introduced species, either the greater number of competing species or some quality of the abiotic environment apparently restricted production of buttercup. While the greasewood and shadscale sites appeared environmentally similar in respect to surface soil characteristics, the buttercup was more prominent under greasewood.

The response of buttercup in crested wheatgrass and western wheatgrass types was quite similar except for production. These two sites also appeared similar as to their relative disturbance.

Bur buttercup was more abundant in the heavily grazed pastures at Benmore. The association of bur buttercup with other species in the grazed pastures indicated a close positive association with the weedy species, halogeton, clasping pepperweed, cheatgrass, and poverty weed. Butttercup is also positively associated with salt-affected halogeton and salt-free sagebrush environments.

Bur buttercup has no forage value for livestock and no evidence suggests that the plant should be enhanced. On the other hand, total elimination is impractical. Local control is possible on cultivated lands simply by cultivation in early spring before seeds have formed.

On rangelands, control by herbicides is possible where valuable perennial species would not be killed by the treatment. Frischknecht has observed that burning after plants have dried will kill the seeds if done before disturbance causes burs to disintegrate.

Competitive and allelopathic effects of bur buttercup on range grasses and wheat were reported by Buchanan and others (1978). Germination studies using both glass and soil systems were used so that results might be extrapolated to field conditions. Three studies were carried out:

An in vitro study in petri dishes was designed to test the effects of leachate from bur buttercup tissue on germination and root growth of grasses. The leachate having an osmotic concentration of 1.8 atmospheres and a pH of 5.5, reduced germination and root growth of crested wheatgrass, tall wheatgrass, winter rye, Gaines fall wheat, and Delmar fall wheat.

The second study involved testing effects of two concentrations of bur buttercup leachate on seven grasses and three forbs in potted silty clay soil from Benmore, plus testing two of the seven grasses in sand. In the silty clay soil, bur buttercup tissue reduced germination of only one species, crested wheatgrass, and only for the heavier concentration of bur buttercup tissue. However, in sand the germination of both species tested (crested wheatgrass and Gaines wheat) was significantly reduced by both concentrations of bur buttercup tissue. The average weight of surviving plants of crested wheatgrass was also reduced by the heavier concentration of buttercup tissue.

The third study involved planting seeds of bur buttercup in the same rows with nine grasses in a cold frame at Benmore. Here bur buttercup significantly reduced growth of fairway and western wheatgrasses. Whether this was due to allelochemic effects or simple competition is unknown. Winter rye and both Gaines and Delmar wheat were far more effective in suppressing growth of bur buttercup than were three of the perennial grass species because they germinated and grew more rapidly than the perennials in the cold frame.

RANGE FERTILIZATION

While many methods have been used to maintain the vigor and density of seeded rangelands, few operators have used fertilizers to improve their lands. A major reason for this is expense. Nevertheless, several studies at Benmore examined the feasibility of applying commercial fertilizers, observed the effects of fertilization, and determined the appropriate application rates.

Guidelines on Fertilization

The fertilization studies have resulted in the following guidelines:

1. Only nitrogen and phosphorus are useful on native perennial rangelands, but because of expense, their use is prohibitive.
2. Carryover from year to year increases with increased rate of nitrogen application. To maintain yields, fertilizers need to be applied almost annually, or at least every 2 years.
3. Nitrogen alone increases forage yields of grasses. Lighter applications of nitrogen yield the same or even more forage than heavier applications.
4. Phosphorus alone seems to produce no significant results on grass except at the higher application rates. Phosphorus also does not significantly improve response due to nitrogen when applied together.
5. Phosphorus does not appear to increase nutritive quality of forage. But nitrogen increases protein, available carbohydrates, and total energy as application rates increase.
6. Fertilization apparently increases production of forage and its use by livestock.
7. Without sufficient rainfall, use of fertilizers may be futile and wasteful.

Levels of Fertilization

Previous fertilization studies show that only nitrogen and phosphorus have any promise on native perennial ranges. Thus, Cook (1965) designed several studies to examine the effects of different rates of nitrogen and phosphorus applications. The nitrogen fertilizer consisted of 33.5 percent ammonium nitrate, and the phosphorus fertilizer was 45 percent treble superphosphate. Cook's studies examined the comparative effects of light and heavy applications of nitrogen and phosphorus at four levels: 20 and 40 lb/acre (22.4 and 44.8 kg/ha); 30 and 60 lb/acre (33.6 and 67.2 kg/ha); 40 and 80 lb/acre acre (44.8 and 89.7 kg/ha); and 90 lb/acre (100.9 kg/ha). On sample plots, nitrogen and phosphorus were applied separately and in all combinations on seeded areas at these rates. The results are revealing.

Yields.—Cook noted that even small amounts of nitrogen alone (20 lb/acre) increased yields the first season after treatment compared to untreated plots. However, phosphorus applications seemed to produce no significant results except at the higher application rates. For example, when 20 lb of nitrogen and 20 lb of phosphate were applied together, slightly less forage was produced than when 20 lb of nitrogen was applied alone. But 40 lb of nitrogen with 40 lb of the phosphate produced more forage than either 20 or 40 lb of nitrogen by itself.

In general, Cook found that in each case the lighter application rate of nitrogen yielded the same or even more forage than the heavier rate. For instance, the 30-lb-per-acre (33.6-kg/ha) rate yielded an increase of 885 lb/acre (992 kg/ha) of forage over unfertilized plots, whereas the 60-lb rate resulted in a 805-lb/acre (902-kg/ha) forage increase. The same results were noted for the 40/80 application rates. When 90 lb/acre (100.9 kg/ha) of nitrogen was applied, plants experienced early wilting and turned brown 2 weeks earlier than untreated plots.

Carryover.—When nitrogen was applied at the lightest application, Cook found no significant carryover beyond the first year. However, carryover became more marked as nitrogen application rates increased. At the 30/60 rates, carryover responses were noted for the next 2 years when treated plots were compared to the untreated plots. Moreover, the most dramatic carryover was found on a deteriorated wheatgrass pasture that,

by the fourth year after fertilization, was still producing 196 lb more forage per acre (219.7 kg/ha) than the untreated plot. Thus, it appears that fertilization can be used to good effect to bring back the vigor on deteriorated grass pastures.

Seedling response.—Neither nitrogen nor phosphorus had any beneficial effect upon seedling emergence, plant survival, or subsequent production when applied at the time of seeding.

Plant growth.—No significant differences were found in leaf length or plant height between fertilized and unfertilized plots. However, the higher rates of nitrogen application increased both crown diameter and number of seed heads per plant. Radial spread of roots was not increased by the increased application of nitrogen. In fact, lateral root development was actually greater for untreated wheatgrass plants. Thus, higher rates of nitrogen application may impede root vigor.

Chemical content of forage.—Phosphate at any rate of application did not appear to affect the nutritive quality or protein content in any way. However, nitrogen applications increased total protein, available carbohydrates, and total energy as application rates increased. For instance, 40 lb (44.8 kg) of nitrogen produced 65 percent more total protein per acre and about 35 percent more total digestible nutrients when compared to unfertilized plots. Ash and cellulose were higher in plants on unfertilized plots.

Recovery efficiency (percent nitrogen).—Most of the recovery of applied nitrogen occurred the first year of application. At the 20/40 level, 80 percent of the nitrogen was recovered the first year. At the the 30/60 level, 70 percent was recovered the first year. The remainder in both cases was recovered over the next 2 years. Cook noted that recovery efficiency decreased as application rates increased.

Utilization.—The application of phosphorus, either at the light or heavy rates, did not increase utilization of either crested or pubescent wheatgrass. However, use was affected by differing rates of nitrogen applications. In all cases, palatability increased with the increased application of nitrogen. As a result, use by cattle increased correspondingly, but the differences practically disappeared by the end of the second growing season after application. Higher applications of nitrogen also appeared to promote more uniform grazing and thus reduced the number of wolf plants in treated pastures.

Soil conditions.—Fertilized plots had less soil moisture during the early summer than did unfertilized plots. Moreover, soil moisture decreased much more rapidly on fertilized plots during the spring and early summer, in large part because there was simply a greater amount of forage growing at a faster rate on the more heavily fertilized plots.

Applications of nitrogen increased the efficiency of soil moisture use compared to untreated plots. Plants on fertilized plots removed 12.37 percent of the moisture and produced 282.3 lb of forage per acre (316.4 kg/ha) for each 1 inch (2.5 cm) of water removed. By contrast, plants on unfertilized plots removed 12 percent of the soil moisture (nearly the same) but produced only 181.1 lb of forage per acre (203 kg/ha) for each inch of water removed—36 percent less forage per inch of water used.

Feasibility of Fertilization

Between 1971 and 1974, Roberts (1977) conducted a study on the economic feasibility of fertilizing rangelands. He hoped to determine (1) the optimum fertilizer reapplication frequency; (2) the most profitable season of application; (3) the most profitable rate of application, including carryover response; (4) livestock responses to fertilization; and (5) costs and returns to ranching operations of range fertilization.

Two pastures at Benmore were fertilized at rates of 0, 25, 50, and 100 lb/acre (0, 28, 56, and 112 kg/ha) and at different seasons of the year. Roberts reported a number of interesting findings.

Forage response.—More than 10 inches (25.4 cm) of annual precipitation is necessary to result in any significant forage response. While levels at Benmore are generally greater than this, operators should be aware that without sufficient rainfall, application of fertilizers may be futile and wasteful. However, Roberts did report that higher rates of fertilization produced plants with wider leaf blades and a darker green color than plants on control sites. Moreover, nitrogen fertilization stimulated early growth in crested wheatgrass. Thus, range readiness of this plant was advanced through fertilization, but strength of response is influenced by levels of precipitation.

Carryover response.—None of the plots studied showed any significant carryover response to fertilization from one season to the next. Thus, to maintain production yields, Roberts concluded that fertilizers would need to be reapplied almost annually or at least every 2 years.

Season of application.—This study was unable to conclusively determine the optimum season of application. Some plots did not respond favorably to initial applications of fertilizers because of inadequate precipitation, and there were no significant carryover effects.

Livestock response.—Fertilization produced an increased carrying capacity on the study sites. The animal unit day (AUD) of grazing changed from 837.76 on unfertilized plots to an average of 1,444.35 on plots fertilized at a rate of 100 lb/acre (112 kg/ha) of nitrogen—an increase of 72 percent. This increased capacity was not too different from plots fertilized at a rate of 50 lb/acre (56 kg/ha), which still resulted in a 60 percent increase of AUD's over unfertilized plots.

This increased amount of grazing led to an increased weight gain for livestock per acre of forage grazed. Calves made the greatest gains while the differences in gains in cows between the different rates of application were not significant.

Roberts concluded that using livestock to harvest fertilized forage on rangelands is economically impractical. Costs of nitrogen fertilizer place it outside economic use by resource managers. In addition, low beef prices also make the use of fertilizers prohibitive. Finally, while the forage may benefit, the effects are temporary and are largely lost after one season.

Other Studies

Frischknecht (1968b) studied effects of commercial fertilizers on plots inside and outside permanent exclosures at Benmore. Nitrogen in the form of ammonium nitrate was applied at the rate of 100 lb/acre (112 kg/ha), phosphate in the form of treble superphosphate at 300 lb/acre (336 kg/ha), and a combined NPK fertilizer in the ratio 6-10-4 to give 100 lb of nitrogen per acre. Applications were made on separate plots in December 1967, January 1968, and March 1968.

The addition of nitrogen produced herbage yields about three times that of untreated plots both inside and outside the exclosures (fig. 21). Phosphorus alone increased herbage yields only about 15 percent. There were no consistent differences in herbage yields between nitrogen alone and the NPK treatment, showing that phosphorus and potassium had little or no effect. Nitrogen increased the number of flower stalks between 5 and 10 times those for untreated plots. Again there were no differences between the nitrogen only and the NPK treatment.

Date of application had little or no effect on herbage yields or numbers of flower stalks, probably because of above average spring precipitation in 1968. A total of 8.38 inches (21.3 cm) precipitation fell between December 13, the first date of nitrogen application, and June 8 when most flower stalks had appeared. Precipitation of 5.68 inches (14.43 cm) fell between March 1 and June 8, which is about 150 percent of the long-term average for this period. There was no appreciable carryover of nitrogen the following year from these applications.

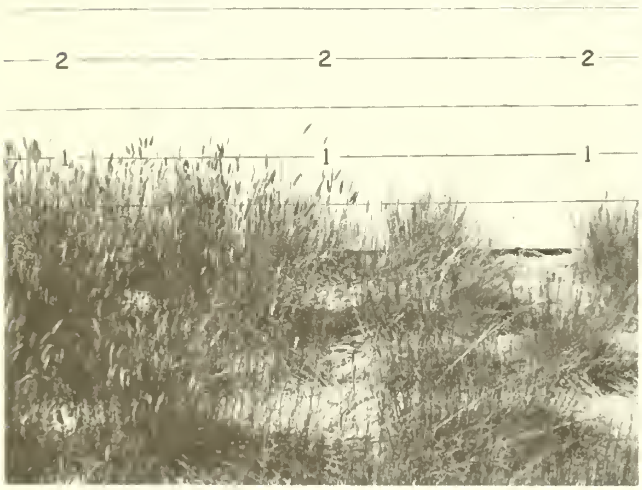


Figure 21.—Fertilized grass (left) shows increased forage and seed stalk production over nonfertilized area (right).

CURRENT RESEARCH AT BENMORE

Although the level of research has tapered off significantly at the Benmore Experimental Range during recent years, the Utah Agricultural Experiment Station continues to use its facilities to conduct a breeding study of interest to range managers and livestock producers.

The Hereford has been the standard beef animal used by livestock operators throughout much of the West. But the livestock production situation has changed dramatically in recent years. Capital and operational costs per cow have increased markedly. Hence, operators are looking for greater returns on their investments. Because the possibility of expanding one's herd size is limited, the alternative has been to improve production per cow by optimizing breeding rates and producing larger calves.

The high production of nutrients of crested wheatgrass during the critical early spring period offers opportunity for using cows of higher milking ability without suffering a penalty of delayed rebreeding. The challenge facing the range cow-calf owner is to balance genetic abilities of cows and calves to the feed production ability of the range.

For these reasons, the Utah Experiment Station is conducting a long-term study to investigate alternatives to straight Hereford breeds. For 3 years (1977 through 1979) Hereford bulls were bred with three selected genotypes of cows: Hereford, Simmental, and Angus. At the conclusion of this first phase, researchers reported that the Hereford-Simmental breed produced a larger calf after 205 days (Stenquist and Bennett 1981). This advantage in weight held true in each of the 3 years, averaging a full 75 lb (34 kg) heavier than the straight Hereford breed and 40 lb (18.1 kg) heavier than the Hereford-Angus combination. Moreover, while the Hereford-Angus combination exhibited the shortest calving interval (357 days), the Hereford-Simmental combination was a close second (359 days). The straight Hereford breed had a calving interval of 367 days. All three groups were satisfactory in this.

This study found that all calves, regardless of breed, sold at equally high prices, and that the Hereford-Simmental cross had slightly higher daily gains in the feedlot. Carcass quality was also equivalent to other breeds. However, the Hereford-Angus cross had some advantages over the other two crosses; it has not shown any cancer eye nor sun-scald—two problems with the straight Hereford and Hereford-Simmental cross.

In the second phase of this study, cows were bred with Charolais and Limousin bulls to produce calves of greater growth potential. Both of these breeds are recognized for their high growth weights. Charolais and Limousin-sired calves had heavier birth weights than the Hereford-sired calves (table 2), but calving difficulty was not high in this study. There was no difference in weaning weight of calves sired by bulls of these two breeds, but their calves were 30, 13, and 31 lb heavier than Hereford-sired calves from Hereford, Angus-Hereford, and Simmental-Hereford cows, respectively (table 3).

In the third phase of this study (Bennett 1984), new genetic material is being added in an attempt to eliminate the cancer eye and sun scald problem while still retaining the high reproductive and high weaning weights as shown by the Hereford-Simmental cross cows. Sires of the Tarentaise breed, a solid red breed with heavy pigmentation around the eyes and on the udder and with good milk production, have been crossed on the cows. Yearlings and calves of the cross show great promise at this stage. These Tarentaise crosses, as cows, will be compared to Angus-Hereford and Hereford-Simmental cows to determine their relative ability as mother cows for this range situation.

Table 2.—Birth weights of crossbred calves (Hereford x Hereford, Simmental x Hereford, Angus x Hereford) in 1980

	Dam			
Sire	**H x H**	**S x H**	**A x H**	**Average**
	Pounds (kg)			
Charolais	85.7 (38.9)	103.2 (46.9)	88.7 (40.2)	92.5 (42.0)
Limousin	81.8 (37.1)	98.5 (44.7)	79.4 (36.0)	86.6 (39.2)
Average	83.8 (38.0)	100.8 (45.7)	84.0 (38.1)	89.6 (40.6)Q

Table 3.—Comparative 205-day weaning weights for Hereford and crossbred dams and Hereford and "exotic" sires

	Sire breed	
Cow breed	**Hereford**	**Charolais and Limousin**
	Pounds	
Hereford	430	460
Angus × Hereford	462	475
Simmental × Hereford	505	536

REFERENCES

Anonymous. WPA history of grazing. Works Progress Administration Writers' Project. MS 8. Logan, UT: Utah State University Archives and Special Collections; n.d.

Baker, Maurice F.; Frischknecht, Neil C. Small mammals increase on recently cleared and seeded juniper rangeland. Journal of Range Management. 26: 101-103; 1973.

Barney, Milo A.; Frischknecht, Neil C. Vegetation changes following fire in the pinyon-juniper type of west-central Utah. Journal of Range Management. 27: 91-96; 1974.

Bennett, James A. Benmore field day report. Logan, UT: Utah Agricultural Experiment Station; 1984. 5 p. Unpublished report.

Bennion, Glynn. Re-grassing the range. National Wool Grower. 14: 19-21; 1924.

Bennion, Harden. The Bennion family of Utah. Vol. 1. Salt Lake City, UT: Bennion Family Association; 1931.

Black, Hal L.; Frischknecht, Neil C. Relative abundance of mice on seeded sagebrush-grass range in relation to grazing. Research Note INT-147. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1971. 8 p.

Blaisdell, J. P. Competition between sagebrush seedlings and reseeded grasses. Ecology. 30: 512-519; 1949.

Bonham, Charles D. The effect of date and rate of application of 2,4-D on control of big and little rabbitbrush. Logan, UT: Utah State University; 1964. 29 p. M.S. thesis.

Buchanan, Bruce A. The life history and ecology of bur buttercup (*Ranunculus esticulatus*). Salt Lake City, UT: University of Utah; 102 p. 1969. M.S. thesis.

Buchanan, Bruce A.; Harper, Kim T.; Frischknecht, Neil C. Allelopathic effects of bur buttercup tissue on germination and growth of various grasses and forbs in vitro and in soil. Great Basin Naturalist. 38: 30-96; 1978.

Castrale, John S. Use of managed sagebrush grasslands by bird populations. Provo, UT: Brigham Young University; 1981. 61 p. Ph.D. dissertation.

Cook, C. Wayne. Crops for diverted dryland wheat acres. Extension Circular 251. Logan, UT: Utah State University Agricultural Experiment Station; 1956. 12 p.

Cook, C. Wayne. Sagebrush eradication and broadcast seeding. Bulletin 404. Logan, UT: Utah State University Agricultural Experiment Station; 1958. 23 p.

Cook, C. Wayne. Plant and livestock responses to fertilized rangelands. Bulletin 455. Logan, UT: Utah State University Agricultural Experiment Station; 1965. 35 p.

Cook, C. Wayne. Development and use of foothill ranges in Utah. Bulletin 461. Logan, UT: Utah State University Agricultural Experiment Station; 1966a. 47 p.

Cook, C. Wayne. Herbicide control of rabbitbrush and sagebrush in mixed stands. Utah Science. Logan, UT: Utah State University Agricultural Experiment Station; 1966b; 27: 9-10, 23.

Cook, C. Wayne; Harris, Lorin E. Nutritive value of cheatgrass and crested wheatgrass on spring ranges in Utah. Journal of Range Management. 5: 331-337; 1952.

Cook, C. Wayne; Leonard, Paul D.; Bonham, Charles D. Rabbitbrush competition and control of Utah rangelands. Bulletin 454. Logan, UT: Utah State University Agricultural Experiment Station; 1965. 28 p.

Cook, C. Wayne; Stoddart, L. A. Seeding ranges to grass. Utah Science. Logan, UT: Utah State University Agricultural Experiment Station; 1947; 8: 10-12.

Cook, C. Wayne; Stoddart, L. A. Seeding ranges to grass requires proper methods and hardy varieties. Utah Science. Logan, UT: Utah State University Agricultural Experiment Station; 1950; 11: 52-53, 56.

Cook, C. Wayne; Stoddart, L. A. Survival of wheatgrass on sagebrush range depends on methods of seeding as well as weather conditions. Utah Science. Logan, UT: Utah State University Agricultural Experiment Station; 1951; 12: 43, 58-60.

Cook, C. Wayne; Stoddart, L. A. Improve foothill ranges. Utah Science. Logan, UT: Utah State University Agricultural Experiment Station; 1959; 20: 5-6, 18.

Cook, C. Wayne; Stoddart, L. A. Nutrient intake and livestock responses on seeded foothill ranges. Journal of Animal Science. 20: 36-41; 1961.

Cook, C. Wayne; Stoddart, L. A.; Sims, Phillip L. Effects of season, spacing, and intensity of seeding on the development of foothill range grass stands. Bulletin 467. Logan, UT: Utah State University Agricultural Experiment Station; 1967. 73 p.

Ferguson, Robert B.; Furniss, Malcolm M.; Basile, Joseph V. Insects destructive to bitterbrush flowers and seeds in southwestern Idaho. Journal of Economic Entomology. 56: 459-462; 1963.

Frischknecht, Neil C. Effect of presowing vernalization on survival and development of several grasses. Journal of Range Management. 12: 280-286; 1959.

Frischknecht, Neil C. Contrasting effects of big sagebrush and rubber rabbitbrush on production of crested wheatgrass. Journal of Range Management. 16: 70-74; 1963.

Frischknecht, Neil C. How far will halogeton spread? Journal of Soil and Water Conservation. 22: 135-139; 1967.

Frischknecht, Neil C. Factors influencing brush invasion of crested wheatgrass range. Bulletin of the Ecological Society of America. 43(3): 53; 1962. Abstract.

Frischknecht, Neil C. Factors influencing halogeton invasion of crested wheatgrass range. Journal of Range Management. 21: 8-12; 1968a.

Frischknecht, Neil C. Factors influencing production of flower stalks in *Agropyron cristatum*. Provo, UT: Brigham Young University; 1968b. 67 p. Ph.D. dissertation.

Frischknecht, Neil C. Biological methods: a tool for sagebrush management. In: The sagebrush ecosystems: a symposium. Logan, UT: Utah State University Press; 1978a: 121-128.
Frischknecht, Neil C. Effects of grazing, climate, fire, and other disturbances on long-term productivity of sagebrush-grass ranges. In: Hyder, D. N. ed. Proceedings of the first international rangeland congress. Denver, CO: Society for Range Management; 1978b: 633-635.
Frischknecht, Neil C.; Baker, Maurice F. Voles can improve sagebrush rangelands. Journal of Range Management. 25: 466-468; 1972.
Frischknecht, Neil C.; Bleak, Alvin T. Encroachment of big sagebrush on seeded range in northeastern Nevada. Journal of Range Management. 10(4): 165-170; 1957.
Frischknecht, Neil C.; Harris, Lorin E. Grazing intensities and systems on crested wheatgrass in central Utah: response of vegetation and cattle. Technical Bulletin 1388. Washington, DC: U.S. Department of Agriculture, Forest Service; 1968. 47 p.
Frischknecht, Neil C.; Harris, Lorin E. Sheep can control sagebrush on seeded range. Utah Science. Logan, UT: Utah State University Agricultural Experiment Station; 1973; 34: 27-30.
Frischknecht, Neil C.; Harris, Lorin E.; Cook, C. Wayne. The Benmore experimental range. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1964. 13 p.
Frischknecht, Neil C.; Harris, Lorin E.; Woodward, Harry K. Cattle gains and vegetal changes as influenced by grazing treatments on crested wheatgrass. Journal of Range Management. 6: 151-158; 1953.
Harris, Lorin E.; Frischknecht, Neil C.; Stewart, George; Bennett, James A.; Woodward, Harry K. Crested wheatgrass provides excellent spring pasture for beef cattle. Utah Science. Utah State University Agricultural Experiment Station; 1950; 11: 71, 93-94.
Harris, Lorin E.; Frischknecht, Neil C.; Sudweeks, Earl M. Extended grazing of crested wheatgrass by cattle: can it be successfully used in summer? Utah Science. Logan, UT: Utah State University Agricultural Experiment Station; 1965; 26: 14-17.
Harris, Lorin E.; Frischknecht, Neil C.; Sudweeks, Earl M. Seasonal grazing of crested wheatgrass by cattle. Journal of Range Management. 21: 221-225; 1968.
Harris, Lorin E.; Raleigh, Robert; Frischknecht, Neil C.; Bennett, James A. Cattle gains and vegetal changes as influenced by grazing treatments on crested wheatgrass. Proceedings of Western Section of American Society of Animal Production. 8: 1-6; 1957.
Havertz, David S. Nematode pathogenicity to crested wheatgrass (*Agropyron cristatum*) at U.S. Forest Service Experiment Station, Benmore, Utah. Salt Lake City, UT: University of Utah; 77 p. 1957. M.S. thesis.
Kearl, Leonard C.; Frischknecht, Neil C.; Harris, Lorin E. Wheatgrass, native grass, and forest grazed by cattle. Proceedings of Western Section of American Society of Animal Science. 22: 63-69; 1971.
Keck, Wendell M.; Frischknecht, Neil C. A well-managed range boosts beef returns. Utah Farmer. 88: 34; 1968.
Kilpatrick, H. M. Heavy grazing during fall and early winter improves sagebrush-grass range. In: Range and livestock management. Reno, NV: University of Nevada Press; 1965.
Knowlton, George F. Range entomology: an important problem of the west. Logan, UT: Utah State University Extension Services; 1966; Mimeograph Series 84. 5 p.
Leonard, Paul D. The influence of *Chrysothamnus nauseosus* on production and vigor of *Agropyron cristatum* and *Agropyron elongatum*. Logan, UT: Utah State University; 53 p. 1964. M.S. thesis.
McArthur, Durant; Tiernan, Charles F.; Welch, Bruce. Subspecies specificity of gall forms on *Chrysothamnus nauseosus*. Great Basin Naturalist. 39: 81-87; 1979.
McKell, Cyrus M.; Chilcote, William W. Response of rabbitbrush following removal of competing vegetation. Journal of Range Management. 10: 228-230; 1957.
Mitchell, George W. Nutritive value of Russian wildrye, crested wheatgrass, and intermediate wheatgrass grazed by cattle on Utah foothill ranges. Logan, UT: Utah State University; 47 p. 1969. M.S. thesis.
Mueggler, W. F. Voles damage big sagebrush in southwestern Montana. Journal of Range Management. 20: 88-90; 1967.
Nichols, D. W. Small rodent populations and biomass in three sagebrush communities of Rush Valley, Utah. Provo, UT: Brigham Young University; 1972. 91 p. M.S. thesis.
Nichols, D. W.; Smith, H. D.; Baker, M. F. Rodent populations, biomass, and community relationships in *Artemisia tridentata* in Rush Valley. Great Basin Naturalist. 35: 191-202; 1975.
Parker, Ronald D. A study of the effects of two conversion treatments on pinyon-juniper vegetation in Utah. Provo, UT: Brigham Young University; 1971. 255 p. Ph.D. dissertation.
Roberts, Dean L. Economics of carry-over forage production, increased grazing season length, and increased livestock production from rangeland fertilization. Logan, UT: Utah State University; 1977. 76 p. M.S. thesis.
Stenquist, Norris J.; Bennett, James A. Optimizing calf weaning weight. Pamphlet EC 395. Logan, UT: Utah State University, Cooperative Extension Service; 1981. 8 p.
Stoddart, L. A.; Cook, C. Wayne. What species of grass for range seeding? Utah Science. Logan, UT: Utah State University Agricultural Experiment Station. 1950; 11: 72-73, 84.
Tingey, Ward M.; Jorgensen, Clive D.; Frischknecht, Neil C. Thrips of the sagebrush-grass range community in west-central Utah. Journal of Range Management. 25: 304-308; 1972.
Vallentine, John F. Look more to wheatgrasses as spring graze. Utah Cattleman. 2: 5, 13-14; 1959.

Walker, Rudger H. Benmore area location of beef cattle investigations. Utah Science. Logan, UT: Utah State University Agricultural Experiment Station; 1944; 5: 6-7.
Warrum, Noble. History of Utah since statehood. Salt Lake City, UT: S. J. Clarke Publishing Company; 1919. 4 vol.

APPENDIX A: HISTORY OF BENMORE

Situated at the foot of the Sheeprock Mountains in west-central Utah, the lands in Rush Valley have experienced over a century of agricultural uses. Like similar areas in the West, this region has witnessed the ebb and flow of human impact on the environment.

Utah's early settlers were farmers first, then ranchers. Early herds were small and most cows provided milk and cheese; beef cattle were much less numerous. Unique among Western States, Utah's ranges were not heavily stocked with Texas longhorns and there were few large livestock operations. The Mormons did not import appreciable numbers of livestock in the mid-1800's. The Mormon Church itself advocated only small herds that could be well cared for and protected near towns from marauding Indians (Anonymous, n.d.).

Benmore was named for two families that exerted a strong influence on the history of Rush Valley: the Bennions and the Skidmores. Arriving in Salt Lake City in 1847, Samuel Bennion settled in what is now known as the Taylorsville area. Bennion's interests were primarily in farming, although he soon began to acquire some livestock. Because livestock herds were small (usually less than 50 head), a cooperative system of management developed among owners. Samuel Bennion joined with a group of other livestock owners in Taylorsville and made a trip in the mid-1850's across the Oquirrh Mountains. Their purpose was to investigate the potential of neighboring Rush Valley for livestock grazing (Bennion 1931). At this time, livestock cooperatives freely ranged their animals on any open lands available, often moving their livestock from one valley to another as the forage was used up (Warrum 1919).

Impressed by the abundance of grass he saw in Rush Valley, Bennion moved his livestock interests into the area in 1858 (Bennion 1931). At this time, western wheatgrass was the predominant species in the valley. According to early records, native grasses were vigorous and occupied both the valleys and benchlands so exclusively and grew so abundantly that it was frequently cut and stacked as hay for winter feed. However, some people scoffed at such efforts, believing that the supply of forage was inexhaustible and such reserves would never be needed. History proved them wrong. Notably, early settlers reported that sagebrush was not prevalent in the valley bottoms, but, like pinyon and juniper, was largely restricted to the foothills (Anonymous n.d.).

In the early years there was little competition for forage between livestock owners, but as numbers of animals increased the range began to show signs of strain. As early as the 1850's, settlers were exhorted to keep their herds small. **The Deseret News** of January 14, 1857, wrote:

> Economy dictates the keeping only such and so many animals as each individual can profitably manage and provide for without depending upon the great uncertainty of winter range. On some ranges cattle are already dying of starvation.

But warnings such as these went largely unheeded. By the 1870's, upwards of 25,000 cattle and horses and an undetermined number of sheep were being summered and wintered in Rush Valley and adjacent Skull Valley (Anonymous n.d.). In the search for more grass, operators moved their herds from one valley to another. Yet, the supply of natural meadow grasses was soon inadequate to the growing herds and advancing frontiers of settlement. Areas near settlements, especially, were too heavily grazed and left nothing to be cut for winter. The depleted range spread in concentric circles from towns anxious to protect their animals from theft. Still, settlers maintained their herds or increased them and ranged their animals farther from towns in search of adequate forage (Anonymous n.d.). Soon, however, ranges where stock could be grazed year-round were exhausted. Given this pattern of continuous overstocking, the native herbaceous species declined and gave way to sagebrush and rabbitbrush.

By 1863, the Bennion livestock interests were well established, but the valley, which reportedly could support almost 10,000 head of livestock (cattle, horses, and oxen) year-round in the late 1850's, was being invaded by sagebrush and juniper. Still, the change was slow and the Bennions and others continued to run large herds in the valley.

In Utah, the era of cooperative herds comprised of many small operators was quickly coming to an end. The 1880's witnessed a consolidation of herds into the hands of a few individuals. This transformation was hastened by the invention of barbed wire in 1881 by Glidden and Ellwood, which brought the days of the free, open range to an end. In addition, droughty summers followed by harsh winters in the mid-1880's (the Great White Disaster) forced many settlers to reduce herd size or sell out completely. The Bennions became one of the few large livestock owners.

About the turn of the century, Rush Valley was considered suitable for another large-scale economic enterprise that was sweeping the West—dry farming. Rush Valley's second most prominent family entered at this time: the Skidmores. In 1905, Charles H. Skidmore and his brother Justin organized the Rush Valley Farming Company, and bought up 10,000 acres (4 047 ha) of land in the valley. The sagebrush-grass range was plowed and dry farms established. Others followed their example. In 1908, more land was acquired but, as before, little of it was irrigated. Winter wheat was planted where dense stands of sagebrush once stood, and when rainfall was good, yields from these farms were fair to good. Yet, during dry years, which occurred frequently, dry farming proved to be highly unprofitable. Many of these farms were abandoned and subsequently taken over by sagebrush.

From 1920 on, the cultivated area in Rush Valley declined in size, especially because the demand for wheat had fallen off drastically after World War I. The area languished, and land that had once supported thousands of head of livestock could scarcely support one-tenth as many in 1924. The sagebrush had taken over the abandoned farm lands so densely that a person had difficulty even walking through the area.

With slightly improved economic conditions in the mid-1920's, farmers moved into the valley, plowed the dense stands of sagebrush, and tried dry farming once more. But nature was conspiring against them. While the long-term average annual rainfall in Rush Valley is almost 13 inches (33 cm), between 1928 and 1935 the average was scarcely more than 9 inches (23 cm)—an amount far below the needs for successful dry farming. In fact, most of the years between 1925 and 1935 were drought years. Thus, farm lands were again abandoned, and sagebrush reinvaded, easily out-competing the depleted perennial grasses.

Through all these years, the Bennions struggled to maintain their livestock interests in Rush Valley. One of the Bennion clan was the first to experiment with management techniques in the early 1920's in an attempt to restore the range to its former productivity. Israel Bennion burned sections of sagebrush during dry seasons and then held livestock off these areas during the growing season. Bennion found that with a few years' protection, the whole burnt area would return to bluestem and bunchgrass. If not protected from grazing, however, weeds and sagebrush quickly reappeared (Bennion 1924).

While Bennion's efforts were noted, they were not generally accepted as good management techniques. Few people really understood enough about rangelands to know what to do. Thus, much of Rush Valley remained dominated by sagebrush that had once been confined to the foothills.

Livestock interests were not faring well. After World War I, especially, there were too many animals on the ranges in Utah and they could not be sold. In 1920 alone, Utah owners reported that over 500,000 head of cattle crowded spring-fall ranges that were already seriously depleted. By the 1930's the depleted, drought-stricken, and poorly managed land led to low calf and lamb crops, lessened carrying capacity, and even poorer range condition. Livestock numbers in Utah up to the 1930's were:

Year	Cattle	Sheep
1885	200,000	1 million
1895	420,000	2 million
1905	350,000	2.6 million
1920	500,000	2.2 million
1930	450,000	3.0 million

Ironically, as the capacity of the range to support livestock declined, numbers of animals were increasing. As one Bennion pioneer put it:

> Rush valley was all a beautiful meadow of grass when we came here with stock in 1860; but in less than 15 years she was all et out, and we had to move to Castle Valley. There you have the history of western grazing in a nutshell. If the range be considered the principal part of the grazers' capital stock, then we grazers have just about finished consuming our capital (Anonymous n.d.).

This pattern of development in Rush Valley was being acted out all over the Western United States. Combined with the Great Depression and "dustbowl" conditions in several Western States, the Federal Government created the necessary machinery to prevent this recurrence of alternate settlement and desertion Between 1934 and 1936, the Agricultural Resettlement Administration established the Central Utah Purchase Project, which acquired land in two old dry farm areas in Utah—Benmore in Rush Valley and Widtsoe in southern Utah near Panguitch. Of the 45,000 acres (18 211 ha) purchased in Rush Valley, over 3,200 acres (1 295 ha) were set aside for research purposes. The experimental site was given the name "Benmore" after the valley's foremost residents and after the small abandoned community of the same name.

APPENDIX B: LIST OF COMMON AND SCIENTIFIC NAMES

Common name	Scientific name
Trees:	
Pinyon pine	*Pinus monophylla*
Utah juniper	*Juniperus osteosperma*
Shrubs:	
Antelope bitterbrush	*Purshia tridentata*
Big sagebrush	*Artemisia tridentata*
Douglas rabbitbrush	*Chrysothamnus viscidiflorus*
Greasewood	*Sarcobatus vermiculatus*
Green rubber rabbitbrush	*Chrysothamnus nauseosus* ssp. *graveolens*
Mountain rubber rabbitbrush	*Chrysothamnus nauseosus* ssp. *salicifolius*
Rubber rabbitbrush	*Chrysothamnus nauseosus*
Shadscale	*Atriplex confertifolia*
Threadleaf rubber rabbitbrush	*Chrysothamnus nauseosus* ssp. *consimilis*
White rubber rabbitbrush	*Chrysothamnus nauseosus* ssp. *albicaulis*
Forbs:	
Bur buttercup	*Ranunculus testiculatus*
Deathcamas	*Zygadenus paniculatus*
Desert globemallow	*Sphaeralcea* spp.
False dandelion	*Agoseris glauca*
Groundsel	*Senecio integerrimus*
Halogeton	*Halogeton glomeratus*
Hawksbeard	*Crepis acuminata*
Hoary phlox	*Phlox hoodii*
Locoweed	*Astragalus cibarius*
Longleaf phlox	*Phlox longifolia*
Low fleabane	*Erigeron pumilus*
Lupine	*Lupinus* spp.
Pepperweed	*Lepidium perfoliatum*
Russian thistle	*Salsola kali*
Utah sweetvetch	*Hedysarum boreale utahensis*
Grasses:	
Bluebunch wheatgrass	*Agropyron spicatum*
Bottlebrush squirreltail	*Sitanion hystrix*
Bulbous bluegrass	*Poa bulbosa*
Cheatgrass	*Bromus tectorum*
Crested wheatgrass	*Agropyron desertorum*
Delmar fall wheat	*Triticum aestivum*
Fairway wheatgrass	*Agropyron cristatum*
Gaines fall wheat	*Triticum aestivum*
Great Basin wildrye	*Elymus cinereus*
Indian ricegrass	*Oryzopsis hymenoides*
Intermediate wheatgrass	*Agropyron intermedium*
Mountain rye	*Secale montanum*
Pubescent wheatgrass	*Agropyron tricophorum*
Russian wildrye	*Elymus junceus*
Sandberg bluegrass	*Poa secunda*
Slender wheatgrass	*Agropyron trachycalum*
Smooth brome	*Bromus inermis*
Tall oatgrass	*Arrhenatherum elatius*
Tall wheatgrass	*Agropyron elongatum*
Thickspike wheatgrass	*Agropyron dasystachyum*
Western wheatgrass	*Agropyron smithii*
Winter rye	*Secale cereale*

U. S. GOVERNMENT PRINTING OFFICE 1984—576-040/10,519 REGION NO. 8

APPENDIX B: (con.)

Mammals:	
Chisel-toothed kangaroo rat	*Dipodomys microps*
Nuttal cottontail	*Sylvilagus nutallii*
Deer mouse	*Peromyscus maniculatus*
Great Basin pocket mouse	*Perognathus parvus*
Blacktail jackrabbit	*Lepus californicus*
Least chipmunk	*Eutamias minimus*
Long-tailed vole	*Microtus longicaudus*
Western harvest mouse	*Reithrodontomys megalotis*
Birds:	
Brewer's sparrow	*Spizella breweri*
Chipping sparrow	*Spizella passerina*
Common bushtit	*Psaltriparus minimus*
Gray flycatcher	*Empidonax wrightii*
Horned lark	*Eremophila alpestris*
Housefinch	*Carpodacus mexicanus*
Lark sparrow	*Chondestes grammacus*
Mountain bluebird	*Sialia currocoides*
Plain titmouse	*Parus inornatus*
Raven	*Corvus corax*
Sage thrasher	*Oreoscoptes montanus*
Scrub jay	*Aphelocoma coerulescens*
Vesper sparrow	*Pooecetes gramineus*
Western meadowlark	*Sturnella neglecta*
Insects:	
Aphid	*Aphis* spp.
Blackgrass bug	*Labobs hesperius*
Cicada	*Cicadidae* spp.
Leaf beetle	*Trirhabda attenuata*
Leaf beetle	*Trirhabda pilosa*
Lepidopterous insects	*Septerova* spp.
Nematode	*Nothotylenchus acris*
Nematode	*Tylenchus davainii*
Nematode	*Tylenchorhynchus dubius*
Sagebrush defoliator moth	*Aroga websterii*
Thrip	*Anaphotrip zeae*
Thrip	*Aptinothrip rufus*
Weevil	*Myrmex lineata knowletoni*
Western flower thrip	*Frankliniella occidentalis*

Astroth, Kirk A.; Frischknecht, Neil C. Managing Intermountain rangelands—research on the Benmore Experimental Range, 1940-84. General Technical Report INT-175. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1984. 44 p.

This paper summarizes research findings from 44 years of research on the Benmore Experimental Range in central Utah and brings together findings previously available in over 80 published and unpublished reports. It provides recommendations for the rehabilitation or improvement, management, and grazing of sagebrush rangelands.

KEYWORDS: range management, range improvement, sagebrush, rangelands, crested wheatgrass, brush control, planting methods, grazing improved ranges

The Intermountain Station, headquartered in Ogden, Utah, is one of eight regional experiment stations charged with providing scientific knowledge to help resource managers meet human needs and protect forest and range ecosystems.

The Intermountain Station includes the States of Montana, Idaho, Utah, Nevada, and western Wyoming. About 231 million acres, or 85 percent, of the land area in the Station territory are classified as forest and rangeland. These lands include grasslands, deserts, shrublands, alpine areas, and well-stocked forests. They supply fiber for forest industries; minerals for energy and industrial development; and water for domestic and industrial consumption. They also provide recreation opportunities for millions of visitors each year.

Field programs and research work units of the Station are maintained in:

Boise, Idaho

Bozeman, Montana (in cooperation with Montana State University)

Logan, Utah (in cooperation with Utah State University)

Missoula, Montana (in cooperation with the University of Montana)

Moscow, Idaho (in cooperation with the University of Idaho)

Provo, Utah (in cooperation with Brigham Young University)

Reno, Nevada (in cooperation with the University of Nevada)

United States
Department of
Agriculture

Forest Service

**Intermountain
Forest and Range
Experiment Station
Ogden, UT 84401**

General Technical
Report INT-176

January 1985

The Limits of Acceptable Change (LAC) System for Wilderness Planning

**George H. Stankey
David N. Cole
Robert C. Lucas
Margaret E. Petersen
Sidney S. Frissell**

THE AUTHORS

GEORGE H. STANKEY is a research social scientist with the Wilderness Management Research Work Unit at the Intermountain Station's Forestry Sciences Laboratory in Missoula, Mont. He received his Ph.D. in geography from Michigan State University in 1970. He is the author of a number of publications on wilderness and recreation management.

DAVID N. COLE is a research ecologist with Systems for Environmental Management, P.O. Box 3776, Missoula, Mont. He is working cooperatively with the Intermountain Station's Wilderness Management Research Work Unit at the Forestry Sciences Laboratory in Missoula. Dr. Cole received his Ph.D. in geography from the University of Oregon in 1977. He has written several papers on wilderness campsite impacts and their management.

ROBERT C. LUCAS is principal research social scientist and project leader of the Intermountain Station's Wilderness Management Research Work Unit at the Forestry Sciences Laboratory in Missoula. He has been with the Station since 1967. Dr. Lucas received his B.S., M.A., and Ph.D. from the University of Minnesota in 1957, 1959, and 1962, respectively. He also studied at the Free University of West Berlin, Germany, and at the University of Chicago. He has authored numerous publications dealing with wilderness management.

MARGARET E. PETERSEN is a research forester at the Intermountain Station's Forestry Sciences Laboratory in Missoula. She received her M.S. in forestry from Oregon State University in 1980. Her interests include recreation use measurement, theories of visitor satisfaction, and visitor management techniques.

SIDNEY S. FRISSELL is associate dean and professor of applied ecology and recreation management at the University of Montana School of Forestry. He holds a Ph.D. in forestry from the University of Minnesota. He has authored a number of papers on recreation and wilderness management.

SUMMARY

This paper describes the Limits of Acceptable Change (LAC) system, a framework for establishing acceptable and appropriate resource and social conditions in recreation settings. The LAC has been developed in response to the need of managers for a means of coping with increasing demands on recreational areas in a visible, logical fashion. The LAC also represents a reformulation of the recreational carrying capacity concept, with the primary emphasis now on the conditions desired in the area rather than on how much use an area can tolerate.

The LAC is not a new idea. It is, however, the latest step in a continuing effort to improve wildland recreation management through definition of more explicit, measurable objectives. Nine steps are involved in the overall process.

Step 1 involves identification of area concerns and issues. In addition to legal guidelines and organizational policy, management of an area needs to reflect area-specific features and values in order that the role of the area at both regional and national levels can be assessed.

In step 2, opportunity classes are defined and described. Opportunity classes represent subunits of the area where different conditions are provided, thereby increasing the diversity of the area. These differences are measured through indicators, identified in step 3, representing resource and social conditions for which management is striving. Indicators should be capable of quantitative measurement.

In step 4, the existing condition of the resource and social conditions is inventoried. These data are recorded and mapped, and serve as the basis for the definition, in step 5, of standards for each indicator in each opportunity class. Basing the standard on inventory data helps ensure realism and also clarifies the nature and extent of management activity that will be required to achieve standards.

Step 6 involves identification of alternative allocations of the area among the various opportunity classes. Because different allocations will require different types of management, step 7 requires an analysis of the various costs and benefits of each alternative, in terms of environmental impacts and impacts on visitors as well as administrative costs.

In step 8, the costs and benefits of each alternative are evaluated and a final alternative is selected. This final selection will reflect the responsiveness of the alternative to the issues and concerns identified in step 1 and the management requirements identified in step 7.

Step 9 involves implementation of the selected alternative and establishment of a monitoring program. Monitoring is particularly important as it provides feedback on the effectiveness of the management actions employed, alerting managers to the need to consider more rigorous application or the use of other measures.

To demonstrate how these nine steps can lead to an effective management program, a hypothetical case example is described.

CONTENTS

The Limits of Acceptable Change (LAC) System for Wilderness Planning

George H. Stankey
David N. Cole
Robert C. Lucas
Margaret E. Petersen
Sidney S. Frissell

INTRODUCTION

A major goal of wilderness management is to maintain or restore the qualities of naturalness and solitude. These qualities, however, are threatened by a variety of human-induced changes from within as well as outside wilderness boundaries. For example, growth in wilderness recreation use, averaging over 4 percent annually for the past 15 years (Petersen 1981), has made protection of these qualities difficult. Similarly, external impacts, such as air and water pollution, threaten these values.

Changes from recreation use could be eliminated if all such use was prohibited. Recreation, however, is a recognized, legitimate use of wilderness and, with a few minor exceptions, such prohibitions are neither possible nor feasible. Even substantial reductions in use are of limited practicality, given that even light use can produce substantial impacts, particularly on vegetation and soils. And, even if eliminating recreation use were possible, human-induced change from nonrecreation sources, both within and outside the area, would remain a problem.

The challenge is not one of how to prevent any human-induced change, but rather one of deciding how much change will be allowed to occur, where, and the actions needed to control it. In this paper, we propose the Limits of Acceptable Change (LAC) system in which the amount of change to be allowed is defined explicitly by means of quantitative standards, the appropriate management actions needed to prevent further change are identified, and procedures for monitoring and evaluating management performance are established.

Recreational Impacts—Focus of the LAC Process

The LAC process requires managers to define desired wilderness conditions and to undertake actions to maintain or achieve these conditions. A variety of influences affect these desired conditions, including recreation, fire control, grazing, and mining. Modern methods of fire detection and control, for example, have led to major departures from natural successional patterns. Implementation of wilderness fire management plans, however, is gradually leading to a restoration of fire to a role more closely resembling natural historic patterns. Grazing and mining impacts can be severe, especially on a local scale, but overall they are minor. For example, a national survey of wilderness managers revealed that seldom were nonrecreational uses a source of problems in more than 10 percent of the areas surveyed. On the other hand, recreation-related problems, either social or biophysical, were a problem in anywhere between one-fourth and three-fourths of the areas (Washburne and Cole 1983).

Thus, our emphasis is on the management of recreational impacts. Recreation use occurs in virtually all wildernesses, whereas many of the so-called "allowable but nonconforming" uses are restricted to only some areas. Recreation is a value endorsed in the definition of wilderness; specific legal provisions legitimize mining and grazing, but they are clearly exceptions to the general purposes of wilderness. Moreover, nonrecreational uses are protected by law and are covered by administrative guidelines; therefore, a land manager's responses to such uses are limited.

Finally, legislative and administrative guidelines on wilderness management emphasize the need to deal with recreation use and its associated impacts on wilderness values. For example, in the regulations implementing the National Forest Management Act (NFMA), Section 219.18(a) states that the portion of forest plans providing direction for wilderness management will: "provide for limiting and distributing visitor use of specific portions in accord with periodic estimates of the maximum levels of use that allow natural processes to operate freely and that do not impair the values for which wilderness areas were created" (Federal Register 1982).

Despite having taken the position that recreation is an appropriate focus of concern for the LAC system, we want to emphasize that we recognize that wilderness management involves more than recreation. The 1964 Wilderness Act reminds us that wilderness is to be managed in such a manner "so as to provide for the protection of these areas (and) the preservation of their wilderness character." The Act goes on to say that "wilderness areas shall be devoted to the public purposes of recreational, scenic, scientific, educational, conservation, and historical use." Clearly, recreation is only one of the purposes of wilderness and is a purpose that can be served only to the extent that the essential wilderness character of the area is protected. Managers are faced, therefore, with the dilemma of having to accommodate human use yet preserving an area's wilderness quality. The LAC process outlined in this paper is intended to provide a framework for dealing with this dilemma.

THE LAC PROCESS

The LAC process gives primary attention to the **wilderness conditions** that exist and that are judged acceptable. Managers are interested in achieving certain conditions and in the relative effects of different management actions to achieve those conditions. Because use levels are of limited value in predicting either social or ecological impacts (Washburne 1982), this process focuses on defining what management actions are needed to achieve certain wilderness conditions. **In summary, the process requires deciding what kind of wilderness conditions are acceptable, then prescribing actions to protect or achieve those conditions.**

Explicit recognition of the importance of providing diverse wilderness conditions and the implementation of management actions to achieve or maintain conditions is also an important part of the LAC process. Given that any use produces at least some impact, the process requires managers to identify where, and to what extent, varying degrees of change are appropriate and acceptable. The conditions that characterize a particular type of opportunity and that distinguish it from others are specified by measurable objectives defining limits of acceptable change (Lime 1970; Frissell and Stankey 1972).

The LAC process consists of four major components: (1) the specification of acceptable and achievable resource and social conditions, defined by a series of measurable parameters; (2) an analysis of the relationship between existing conditions and those judged acceptable; (3) identification of management actions necessary to achieve these conditions; and (4) a program of monitoring and evaluation of management effectiveness. These four components are broken down into nine steps to facilitate application.

This process can substantially improve wilderness management. For Forest Service managers it will satisfy several NFMA mandates: it follows general planning guidelines, establishes a monitoring program, and, where necessary, provides estimates of maximum levels of use. The basic features of the planning process can also be applied to wildernesses managed by other Federal and State agencies.

The LAC approach to wilderness planning is not a new idea. It represents the latest step in efforts to improve definition of both inputs to and outputs from the planning process. It derives from a management-by-objectives (MBO) approach to planning and is conceived of as a dynamic, continuing process. Such an approach is described in Hendee and others (1978) and is related to the design capacity idea discussed by Godin and Leonard (1977) and to the framework described by Frissell and others (1980).

The Procedure

The planning procedure consists of a series of interrelated steps leading to development of a set of measurable objectives that define desired wilderness conditions (see fig. 1). It also identifies the management actions necessary to maintain or achieve those conditions.

As presented here, the LAC is only a conceptual process—not policy. It requires field application by managers who will, through their experience, modify it and improve upon it. From such experience, wilderness management agencies will be better able to incorporate the LAC into their particular resource management decisionmaking machinery.

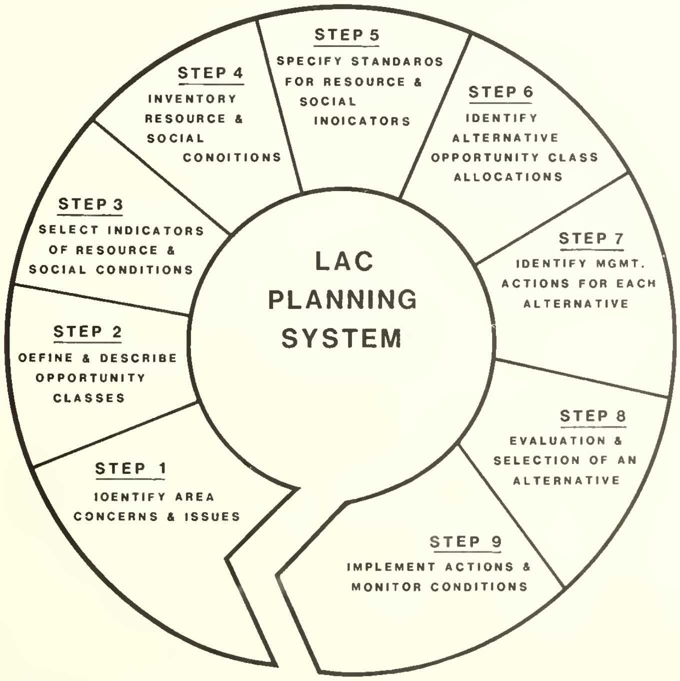


Figure 1.—The Limits of Acceptable Change (LAC) planning system.

STEP 1: IDENTIFY AREA ISSUES AND CONCERNS

The purpose of step 1 is to identify those public issues and managerial concerns that relate to (1) distinctive features and characteristics of the wilderness area and (2) the relationship of the individual area to other units of the wilderness system and to nonwilderness areas offering primitive recreation opportunities. General management direction for every wilderness is based on the Wilderness Act, related legal guidelines, and organizational policy. This step builds on that foundation, refining management direction to deal with the specific situation in each area.

In step 1, managers could consider matters such as:

1. Does the area contain outstanding ecological, scientific, recreational, educational, historic, or conservation values that warrant special attention?
2. Does the area provide critical habitat for threatened or endangered species?
3. Has public input identified areas or issues that merit special attention?
4. Do land uses on contiguous areas represent situations requiring special management attention (are timber harvests planned, are changes in access likely)?
5. Are there existing or potential nonconforming uses in the area that will require special attention?
6. Are there regional and/or national issues that need consideration:
   a. What is the availability of wilderness and dispersed recreation opportunities in the planning region?
   b. What is the regional demand for wilderness and dispersed recreation?
   c. Are the physical-biological features of the area found elsewhere in the region or does it possess unique features?
   d. Are the types of recreation opportunities offered by the area available in other wildernesses or does the area offer opportunities not found elsewhere (are opportunities for long-distance backcountry horse riding available in many other areas or just this one)?

Answers to such questions help managers identify the values of the area and its role in the region and in the Wilderness System. For example, in a large wilderness with a stable grizzly bear population and a healthy ecosystem to support it, managers might emphasize ecosystem protection and minimize human disturbance. In another area, management direction might feature maintenance of outstanding opportunities for horse use (fig. 2). Establishing such area-specific direction maximizes the diversity of resource and social conditions provided by the Wilderness System.

There will be varying abilities to answer these questions and varying levels of detail developed in response to them. Managers should remember that the purpose here is to gain a better understanding of the role of the area in a larger regional setting and not let the inability to perform a comprehensive analysis hold up completion of the step.

Some issues and concerns identified in step 1 might be incompatible. For example, managers might identify solitude as a major value in the area, while there is public support for increased access. There is no simple way of resolving such conflicts. The inevitable diversity of tastes and preferences highlights the importance of examining individual wildernesses within a regional framework. In step 6, managers can accommodate these diverse concerns as they allocate the area to different opportunity classes.

Figure 2.—Some areas may provide special provisions for horse use.

In summary, step 1 involves the following purposes, processes, and products:

PURPOSE

- To identify features or values of particular concern to be maintained or achieved
- To identify specific locations of concern
- To provide a basis for the establishment of management objectives
- To guide the allocation of land to different opportunity classes

PROCESS

- Identify issues raised during public involvement
- Identify concerns raised by resource managers, planners, and policymakers
- Review agency policy
- Analyze regional supply and demand
- Analyze opportunities in the area from a regional and national perspective

PRODUCT

- Narrative writeup identifying unique values and special opportunities to be featured in area's management and problems requiring special attention

STEP 2: DEFINE AND DESCRIBE OPPORTUNITY CLASSES

In step 2, we define a series of **opportunity classes** for the wilderness. An opportunity class provides a qualitative description of the kinds of resource and social conditions acceptable for that class and the type of management activity considered appropriate. Opportunity classes are not on-the-ground allocations, nor are they derived from specific conditions found within the area. They are, instead, hypothetical descriptions of the range of conditions that managers consider likely to be maintained or restored in the area. The opportunity class definition provides a rationale against which the appropriateness of indicators (step 3), standards (step 5), and management actions (step 7) can be tested.

The designation of opportunity classes follows the basic Recreation Opportunity Spectrum (ROS) system (USDA Forest Service n.d.; Buist and Hoots 1982; Driver and Brown 1978; Clark and Stankey 1979a). As presently used, the ROS defines six classes: Primitive; Semiprimitive Nonmotorized; Semiprimitive Motorized; Roaded Natural; Rural; and Urban. Typically within wilderness areas, the Primitive and Semiprimitive Nonmotorized classes would apply. In general terms, these two classes can be characterized as follows:

Primitive
Area is characterized by essentially unmodified natural environment of fairly large size. Interaction between users is very low and evidence of other users is minimal. The area is managed to be essentially free from evidence of human-induced restrictions and controls. Motorized use within the area is not permitted.

Semiprimitive Nonmotorized
Area is characterized by a predominantly natural or natural-appearing environment of moderate-to-large size. Interaction between users is low, but there is often evidence of other users. The area is managed in such a way that minimum onsite controls and restrictions may be present, but are subtle. Motorized use is not permitted.

These setting descriptions are broad and within each it is possible to describe several subclasses. For example, at major entry points, use levels can be relatively high, with fairly frequent contact among parties. Similarly, resource impacts can be moderately substantial in these areas. Elsewhere in the same wilderness there are areas where few visit and where ecological conditions are almost undisturbed. Between these extremes there is a continuum of conditions, all within the wilderness. It would be very difficult to eliminate this internal variability, short of a highly regulated system of entry. Thus, managers need to consider provision of a range of conditions within wilderness boundaries to achieve resource and social objectives.

Step 2 requires managers to select and name a set of opportunity classes that reflect the range of conditions they wish to provide in the area. In small areas, perhaps only one class would suffice, while in large areas, perhaps four to six would be needed. In choosing classes, managers need to consider both the range of conditions that exist as well as the conditions they might want to achieve.

An Example of Opportunity Class Definitions

Resource conditions typically include the type and extent of recreational visitor impacts. In writing statements regarding acceptable resource conditions for each opportunity class, managers should address the following considerations:

1. Type of impact
2. Severity of impact
3. Prevalence and extent of impact
4. Apparentness of impact (extent to which impact is noticeable to visitors).

To contrast the kinds of resource conditions judged appropriate for different opportunity classes, consider the following statements written for a 'pristine' opportunity class (fig. 3) and a 'transition' opportunity class. These two opportunity classes represent the extremes for a spectrum that includes pristine, primitive, semiprimitive, and transition classes. Other terms are possible and our use of these is for illustrative purposes.

Figure 3.—Areas managed as pristine should show minimal human impact.

Pristine	Transition
Resource impacts are minimal; restricted to minor temporary loss of vegetation where camping occurs and along some travel routes. Impacts typically recover on an annual basis and are subtle in nature, generally not apparent to most visitors.	Resource impacts found in many locations and some can be substantial in a few places such as near major entry points. Impacts often persist from year to year. May be substantial loss of vegetation and soil at some sites. Impacts are readily apparent to most visitors.

Social conditions must also be covered in the description. Hence, managers should consider levels and types of encounters occurring in the opportunity class. Specifically, the description should address:

1. Extent of interparty contact
2. Location of interparty contact.

Again, to compare conditions in a pristine opportunity class with those in a transition opportunity class, consider the following:

Pristine	Transition
Few, if any, contacts with other groups. Contact limited to trails; camping out of sight and sound of others almost always possible.	Contact with others moderately frequent. Fairly high level of interparty contact can occur, both while on the trail and while camped.

Such descriptions describe very different kinds of social settings for these two opportunity classes. They indicate that the pristine opportunity class will provide high levels of solitude while the transition opportunity class is an area of use concentration and fairly frequent contact.

Finally, managers need to provide descriptive statements of managerial conditions. The managerial condition is an especially important part of the description because it establishes a framework for what will be done to achieve resource and social conditions. A clear description of appropriate management conditions is important because standards will not be prescribed in step 5 as they are for desired resource and social conditions. Why? Because management conditions deal primarily with the means by which the resource and social conditions, as expressed in the standards, will be achieved. A carefully developed description addresses the following kinds of management issues:

1. Presence of management personnel
2. Onsite versus offsite management strategies
3. Site modification
4. Rules and regulations on behavior.

Comparing the managerial settings in the pristine opportunity class with those in the transition opportunity class, the descriptors might read as follows:

Pristine	Transition
Direct onsite management of visitors not practiced. Little or no evidence of site management. Necessary rules and regulations communicated to visitors outside the area. Little evidence of management personnel.	Extensive use of onsite management and site modification. Rules and regulations enforced with signs and management personnel in the area. Substantial use of regulations to influence visitor behavior.

Collectively, these narrative descriptions of the resource, social, and managerial conditions for each opportunity class constitute the **management objectives** for the area. They describe the conditions sought in the wilderness and serve as criteria for identifying what and where specific management actions are needed (Hendee and others 1978). These objectives serve throughout the process to determine what types of information are needed, what standards need to be developed, the appropriateness of various activities, and what management actions need to be instituted.

The purpose, process, and product of step 2 can be summarized as follows:

PURPOSE

- To facilitate the provision and maintenance of inter- and intra-area diversity

PROCESS

- Review information collected during step 1 concerning area issues and concerns and select number and names of opportunity classes

PRODUCT

- Narrative descriptions of resource, social, and managerial conditions defined as appropriate and acceptable for each opportunity class

STEP 3: SELECT INDICATORS OF RESOURCE AND SOCIAL CONDITIONS

The preceding two steps provide managers with generalized descriptors of the desired condition. In step 3, we move on to identify indicators—specific variables—that, singly or in combination, are taken as indicative of the condition of the overall opportunity class. Such measures allow managers to unambiguously define desired conditions and to assess the effectiveness of various management practices.

To develop these more specific statements, managers need to first review the broadly defined issues and concerns in step 1 that require attention. For example, there might be concern with issues such as excessive use levels along trails in the area or with the amount of biophysical impact at campsites. We can describe these broad categories of issues or concerns as **factors**. The following list covers likely topics:

Suggested Resource and Social Factors

Resource	Social
1. Trail conditions	1. Solitude while traveling
2. Campsite conditions	2. Campsite solitude
3. Water quality	3. Conflicts between visitors with different travel methods
4. Air quality	4. Conflicts regarding party size
5. Wildlife populations	5. Noise
6. Threatened and endangered species	
7. Range condition	

Within these broad categories, however, managers will need to identify one or more indicators that reflect the overall condition of the factor. For example, campsite condition encompasses a number of concerns; what specific indicators should be selected for measurement? Criteria that can help guide selection of indicators would include:

1. The indicator should be capable of being measured in cost-effective ways at acceptable levels of accuracy.
2. The condition of the indicator should reflect some relationship to the amount and/or type of use occurring.
3. Social indicators should be related to user concerns.
4. The condition of the indicator should be, at least potentially, responsive to management control.

Thus, indicators that could be used to measure campsite condition might include total area of bare ground, number of damaged trees in the campsite area, soil compaction, or a composite index reflecting overall campsite condition. For a factor such as campsite encounters, indicators might include the number of other persons camped within sight or sound or the total number of sites located within some unit area.

There are many publications that are useful in identifying indicators and in deciding how information on that indicator can best be collected. A general discussion of the concept of indicators is found in van der Smissen (1975). For campsite conditions, readers are urged to review Frissell (1978); Hendee and others (1976); Cole (1981, 1982, 1983); Cole and Schreiner (1981); Cole and Dalle-Molle (1982); Bratton and others (1978); Parsons and MacLeod (1980). Resource conditions along trails are discussed in Dale and Weaver (1974); Weaver and Dale (1978); Leonard and Whitney (1977); Cole (1982); Cole and Schreiner (1981); Helgath (1975). Publications on water quality include Barton (1969); McFeters (1975); Silverman and Erman (1979); Taylor and Erman (1979, 1980); King (1971); Stanley and others (1979). Sanitation impacts are discussed in Leonard and Plumley (1979); Stanley and others (1979); Temple and others (1980, 1982). Discussions of wildlife impacts are in Ream (1979, 1980); Neil and others (1975).

Many papers explore the question of acceptable and appropriate contact levels along trails and at the campsite. Examples would include Stankey (1973, 1980); Lee (1977); Absher and Lee (1981); Bultena and others (1981); West (1981); Schreyer and Roggenbuck (1978); Shelby (1980). Helpful information on how such information might be collected is found in Leonard and others (1980); Shechter and Lucas (1978). Discussion of conflicts concerning noise levels can be found in Dailey and Redman (1975); Clark and Stankey (1979b); Harrison and others (1980).

Probably no single indicator constitutes a comprehensive measure; it will reflect only a portion of what the objective seeks to achieve. For example, if provision of outstanding opportunities for solitude is the objective, managers might use indicators such as the number of interparty contacts while on the trail or while at the campsite. If, for example, interparty contacts can be held to two or less per day while traveling, the objective of providing outstanding opportunities for solitude presumably has been attained. Other factors, such as whether contact is with a horse or hiker party, also influence whether or not the objective is achieved. Thus, two or more indicators can be used as a way of comprehensively measuring performance in terms of the objectives.

It is important to select indicators that relate as directly as possible to the objective. For example, managers might select use density (visitor-days per 1,000 acres or hectares) as the indicator for a solitude objective. Varying density levels would be specified as standards for the different opportunity classes. The linkage between density and subsequent interparty contact levels is indirect and weak, however, especially for dispersed recreation opportunities. Thus, the choice of density as an indicator would be less useful than a contact indicator directly related to solitude.

In summary, step 3 involves the following:

PURPOSE

- Identify specific variables to guide inventory process (step 4)
- Provide basis for identifying where and what management actions are needed

PROCESS

- Review information outlined in descriptions (step 2)
- Review issues and concerns regarding specific conditions identified in step 1 and select factors that reflect these issues and concerns

PRODUCT

- List of measurable resource and social indicators (preferably quantifiable)

STEP 4: INVENTORY EXISTING RESOURCE AND SOCIAL CONDITIONS

The inventory is guided by the indicators selected in step 3. The indicators specify the variable(s) inventoried; they also identify the unit of analysis. For example, managers might be concerned about water quality. In selecting indicators that will define water quality standards, they might select coliform counts in lakes or streams adjacent to campsites. Thus, the resulting water quality inventory has a specific focus that defines what data are to be collected and where. During the inventory, data need to be collected that provide information on the coliform counts throughout the area.

To be of value to managers, the inventory must be conducted in an objective and systematic fashion. If not, the data will be of limited value.

Inventory data provide managers with the range of conditions of the indicators. Such information can be recorded directly onto base maps, providing easy analysis of its spatial patterns. This will be helpful when, in step 6, managers consider different allocations of opportunity classes across the area, as it facilitates comparison between existing conditions and those defined as acceptable for an opportunity class.

Resource inventories can be conducted at different levels of detail. Often, managers will have inventory data from previous fieldwork or they may have partially completed inventory data (fig. 4). While it is obviously most desirable to have an up-to-date comprehensive inventory of the condition of the selected indicators, managers may have to work with data that are less than complete or current. Where this is the case, the limits of the data should be carefully documented and an improved data base should be a priority in scheduling the monitoring phase in step 9.

Step 4, in summary, involves the following:

PURPOSE

- Knowing the range of conditions helps establish meaningful standards
- Helps in decisions on allocations of land to different opportunity classes
- Critical step to knowing where and what management actions will be needed

PROCESS

- Conduct field inventory of conditions of resource and social indicators and map resulting information

PRODUCT

- Map of existing conditions of each indicator throughout the wilderness

Figure 4.—Inventorying campsite condition is an important step in the LAC system.

STEP 5: SPECIFY STANDARDS FOR RESOURCE AND SOCIAL INDICATORS FOR EACH OPPORTUNITY CLASS

In step 5, the task is to assign quantitative or highly specific measures to the indicators. This greater specificity is obtained by establishing **standards**—measurable aspects of the indicators defined in step 3. These standards provide a base against which a particular condition can be judged as acceptable or not.

Using data collected in step 4, it is possible to specify standards that describe the acceptable and appropriate conditions for each indicator in each opportunity class. Setting standards is a judgmental process; however, the process is logical, traceable, and subject to public review.

Standards are not just idealistic goals; they are conditions that managers feel can be achieved over a reasonable time. In some cases, standards might be merely statements of current conditions. In other cases, standards can be written to purposively direct modification of wilderness conditions, typically, but not necessarily, towards a more natural state.

Basically, then, standards should be stringent enough to be meaningful, but not so stringent they cannot be attained.

Three general guidelines apply to the process of establishing standards:

Standards Follow Descriptors

The qualitative descriptions developed in step 2 provide clues as to the kinds of conditions characterizing each opportunity class. For example, if

a description written for a "transition" zone suggests that "contacts are fairly frequent while traveling," managers could use the inventory data to help specify how "fairly frequent" might be quantitatively defined. The inventory data might show that contact levels on trails near major entry points average 10 to 15 parties per day. These data could be utilized to help set the standard for the "average contacts with others per day" indicator to define the transition opportunity class.

It is important that the standards not routinely accommodate existing conditions. For example, there will be places where existing conditions have deteriorated to the point that they no longer represent acceptable wilderness conditions, despite the area's legal classification. In such cases, managers are legally bound to restore these areas to a condition that is, at **the minimum**, acceptable in wilderness. The LAC process in no way condones maintenance of conditions unacceptable in wilderness. And, even if existing conditions are judged as minimally acceptable, managers should seek opportunities to improve them through establishment of more stringent standards.

In formulating standards, there needs to be a balance between using existing conditions to lend realism to the specific standards on the one hand, and using professional judgment along with public input to set the standards at levels that can lead to an improvement in conditions.

Standards Describe a Range of Conditions

As one moves across the opportunity classes for any given indicator, the standards should describe a logical progression or gradation of conditions. For example, managers might select "other parties camped within sight or sound at night" as an indicator for solitude. In the pristine opportunity class, the description might read "very high chances for solitude." For this class, a standard of "no other parties camped within sight or sound" might be prescribed. Then, moving on to the other opportunity classes and remembering that the intent is to provide a logical progression or gradation of conditions relative to this particular indicator, managers might set standards of "no more than 1," "no more than 2," and "no more than 4," for the primitive, semiprimitive, and transition opportunity classes, respectively.

On occasions, the standards set for an indicator might be shared by two or more opportunity classes; however, they will be distinguished by other indicators. For example, the standards set for an indicator such as "number of other parties camped within sight or sound" might be the same for the "primitive" and "semiprimitive" opportunity classes. Shared standards are particularly appropriate where the range of conditions is low. Again, the descriptors will help managers decide when shared standards should be adopted.

While a progression of standards across opportunity classes will be typical, there might be certain conditions that apply areawide and that do not discriminate between classes. Examples include air quality and water quality. Also, baseline standards might prescribe conditions that must be met in all areas; namely, under no situation could a condition in a wilderness fall below this baseline standard. Regionwide standards have been implemented in Forest Service Regions 2 and 6 and provide managers with a clear guideline as to minimum performance standards. Such baseline standards do not preclude more stringent standards within individual areas.

Standards Express the Typical Situation

Standards are often best expressed in terms of probabilities. For example, a standard for daily contacts while traveling in the primitive opportunity class might be expressed as: "Interparty contact levels on the trail will not exceed two per day on at least 90 percent of the days during the summer use period." This recognizes the fact that the high degree of resource and social variability in a complex wilderness system often makes specific, absolute standards unrealistic.

Choosing indicators and writing standards are crucial steps as they, to a great extent, determine the future character of the wilderness. Public input, research information, and managerial experience will be helpful guides. There is no need, however, to be paralyzed by concerns as to whether the "right" indicators have been chosen or whether the standards are "correct." As noted earlier, the process is judgmental and state of the art (Clark 1982). Because monitoring and evaluation are an integral part of this procedure, management will be able to revise indicators and standards in response to improved information. Moreover, the judgments are made in a visible fashion so that they can be reviewed by others.

In summary, step 5 involves the following:

PURPOSE

- To provide a means whereby it is possible to evaluate where and what management actions are needed by permitting comparison of existing conditions with those defined as acceptable for each indicator in each opportunity class

PROCESS

- Review opportunity class descriptions developed in step 2
- Analyze inventory data collected in step 4 for each indicator

PRODUCT

- A table of specific (quantified where possible) measures of acceptable conditions for each indicator in each opportunity class

STEP 6: IDENTIFY ALTERNATIVE OPPORTUNITY CLASS ALLOCATIONS REFLECTING AREA ISSUES AND CONCERNS AND EXISTING RESOURCE AND SOCIAL CONDITIONS

The objective in step 6 is to decide what resource and social conditions (in the form of specific standards) are to be maintained or achieved in specific areas of the wilderness. This is a prescriptive step (it is concerned with establishing what **should** be), and input from both managers and the public should be used to make these decisions. Step 6 initially involves an analysis of the inventory data collected in step 4, along with the area issues and concerns identified in step 1. These issues and concerns, however, do not prescribe what should be done. They have to be balanced against the realities of what exists, as revealed by the maps of existing condition for each indicator, as well as what is possible in terms of agency resources.

Maps of alternative opportunity classes, reflecting both area issues and concerns and existing resource and social conditions, result from step 6. Some issues might prove mutually contradictory ("increase opportunities for easier access into most portions of the wilderness" and "provide greater opportunities for solitude"). Managers could respond in a variety of ways. They might attempt to provide the full range of opportunity classes in sufficient amounts to satisfy the varying demands. Or, they might elect to manage primarily for only a couple of the opportunity classes, on the grounds that the other classes are adequately represented elsewhere in the region. Finally, they might propose a variety of manage-

ment alternatives that reflect a range of opportunity class mixes. Through such variations, it would be possible to offer a diverse range of conditions for public review and consideration.

The LAC Process and the Concept of Nondegradation

The relationship of the LAC process to the concept of nondegradation merits special comment. One possible opportunity class allocation might involve a decision to allow a change in resource or social conditions. Managers might accommodate higher use levels in an area where current resource conditions show little human modification. To let use levels rise will mean that resource conditions will deteriorate from their currently pristine character. Similarly, current low levels of contact among recreationists likely will rise.

The nondegradation concept calls for maintenance of present resource conditions if they equal or exceed minimum standards and the restoration of below-minimum levels. Applied to wilderness, the concept seeks to prevent degradation of current naturalness and solitude in each wilderness and to restore substandard settings to minimum levels (Hendee and others 1978). Thus, a management alternative such as that outlined above apparently would violate the nondegradation concept.

While accepting the essential features of the nondegradation concept, there are some important related issues that need to be considered. First, a major rationale underlying application of the concept to wilderness is to prevent the conditions found in some heavily used wildernesses (fig. 5) serving as the minimally acceptable level to which other areas would be allowed to deteriorate. In other words, these heavily impacted areas were not to serve as a precedent for conditions elsewhere.

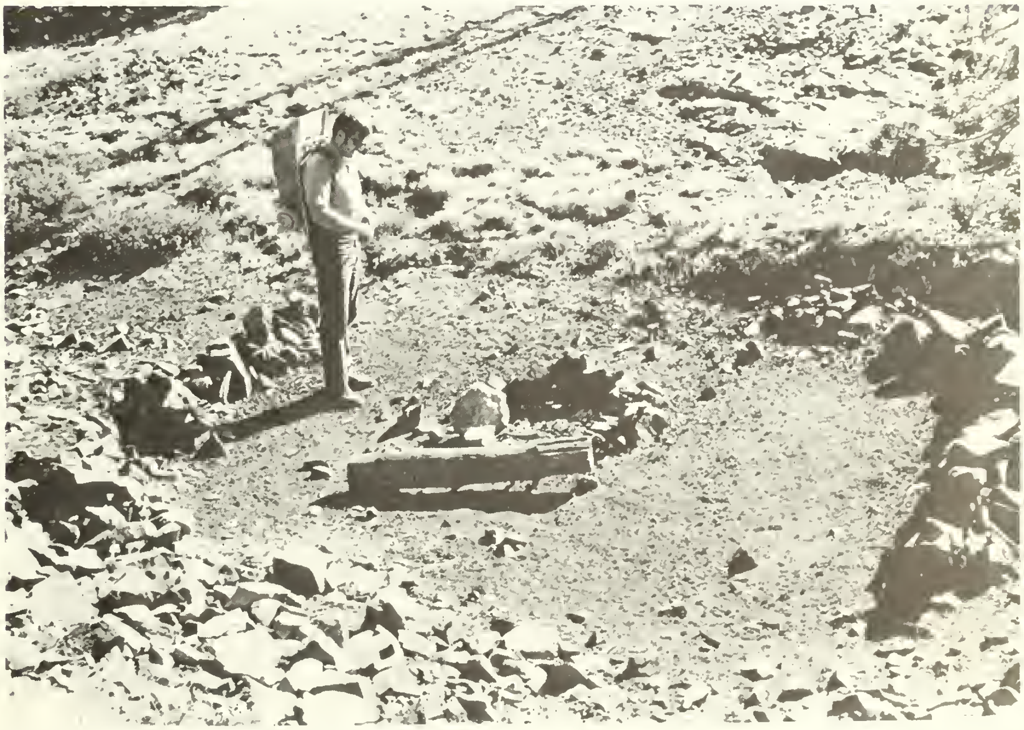


Figure 5.—Heavily impacted campsites detract from the wilderness experience.

Second, with rigorous application of the nondegradation concept, current conditions would set a base below which standards could not be set (they could be set higher). Future recreational demands thus could not be accommodated in opportunity classes where current conditions are very high, as the impacts associated with this demand would result in the standards being exceeded.

While application of the nondegradation concept throughout a wilderness would ensure long-term preservation of areas where pristine conditions currently exist, it would also accelerate the imposition of stringent management actions, such as rationing.

Protection of pristine conditions is important, particularly because once lost, such conditions cannot be regained in any reasonable time span. At the same time, to never allow conditions to become more impacted than at present imposes certain implications and costs on managers and visitors alike. It is our view that alternatives that involve acceptance of increased impact levels be carefully considered. The LAC process facilitates such consideration by outlining the various costs and benefits and by identifying what management actions will be needed to accomplish objectives.

In summary, step 6 involves the following:

PURPOSE

- A step toward defining what resource and social conditions will be provided in different parts of the wilderness
- Provision of allocation alternatives for public review and evaluation

PROCESS

- Review information obtained from area issues and concerns, step 1
- Review information contained in opportunity class descriptions, step 2
- Review information derived from inventory of existing conditions of indicators, step 4

PRODUCT

- Maps and tabular summaries of alternative opportunity class allocations

STEP 7: IDENTIFY MANAGEMENT ACTIONS FOR EACH ALTERNATIVE

After alternative packages of opportunity classes have been formulated, managers need to identify the differences, if any, that exist between current conditions (inventoried in step 4) and the standards (identified in step 5). This will identify places where problems exist and what management actions are needed. Then managers need to consider what actions will be instituted to achieve the conditions specified by each alternative and to evaluate the costs and appropriateness of implementing these actions. If an alternative calls for a set of opportunity areas that closely match the current situation, the management actions needed to achieve this might not be too costly. On the other hand, if a major change is proposed, the needed management might involve considerable costs.

Where existing conditions are better than standards, there is little need for change in management, although there might be a need to evaluate whether existing actions should be changed or eliminated. Where conditions are close to or substantially worse than standards, managers must consider new actions.

For any given alternative, there likely will be a number of possible management actions that could be undertaken to achieve the standards. The qualitative descriptions for each opportunity class developed in step 2

serve as guidelines as to whether or not a particular management action is appropriate. However, these descriptions are not iron-clad rules—they are guidelines, not standards. As a general rule, apply the "principle of minimum regulation" (Hendee and others 1978); use only that level of control necessary to achieve a specific objective.

If existing resource and social conditions are consistent with the opportunity class designation, then the management actions typically should be consistent with that designation. If, on the other hand, the existing resource and social conditions differ from those desired, then the management actions needed to achieve those standards, consistent with the necessity and minimum regulation proviso, should be employed, even if they are not consistent with the management condition descriptor written in step 2.

For example, if a currently heavily impacted area were to be converted to a pristine condition, intensive management would be needed. Such a program might include restrictions on where and how long visitors could camp, restriction of recreational stock, and closures of certain areas (fig. 6). Normally, such actions would be inappropriate in the pristine opportunity class, but without such measures it would be difficult to achieve management objectives in any reasonable time span. Hence, more restrictive management is imposed until appreciable gains are made toward achieving the standards.

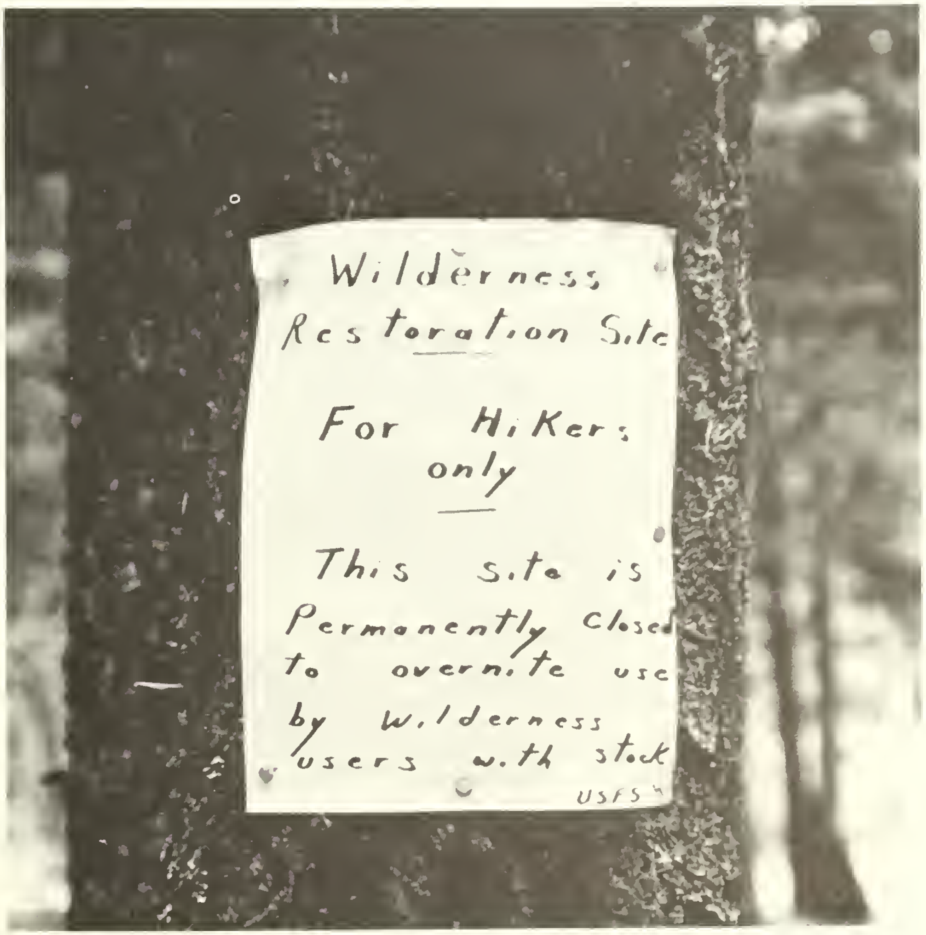


Figure 6.—Camping areas may be closed to allow revegetation.

Managers should remember that standards define minimally acceptable conditions sought in an area. Nevertheless, such standards do not preclude providing protection in part of an opportunity class above that specified by the standards. Many areas consist of frequently visited valley-bottom trail corridors bounded by trailless, relatively pristine valley walls. By maintaining conditions better than the standard requires, further diversity in wilderness conditions is achieved.

In summary, step 7 involves the following:

PURPOSE

- Step toward evaluating the costs of implementing each alternative
- Step toward selecting a specific management program

PROCESS

- Review the managerial condition portion of the opportunity class description defining the appropriate types of actions
- Analyze the differences between existing conditions and those defined as acceptable by the standards
- Analyze the alternative management actions for bringing existing conditions in line with standards

PRODUCT

- List or map of all places where existing conditions are worse than standard and identification of what management actions would best bring conditions up to standard

STEP 8: EVALUATION AND SELECTION OF A PREFERRED ALTERNATIVE

The selection of a preferred alternative will reflect the evaluation of both managers and concerned citizens. There is no simple formula regarding how such a decision is made. Some questions to guide this selection are:

1. What user groups are affected and in what ways (does it facilitate or restrict use by certain groups)?
2. What values are promoted and which are diminished?
3. How does a particular alternative fit into the regional and/or national supply and demand considerations? Does the alternative contribute a unique kind of wilderness setting to the system?
4. What is the feasibility of managing the areas as prescribed, given constraints of personnel, budgets, etc.?

In the analysis of the alternatives, a variety of costs need to be considered. These would include the financial costs (personnel, materials), information costs (costs associated with acquiring information needed to implement actions), opportunity costs associated with not carrying out a proposed action, and other resource and social costs. These latter costs are difficult to quantify, particularly in monetary terms, but they are extremely important (Lucas 1982).

While it is difficult to measure the costs and benefits of the various alternatives, their presence or absence usually can be identified. For example, managers usually can identify the kinds of costs (e.g., increased impacts on vegetation) and benefits (e.g., increased opportunities for solitude) associated with a management action. Even though it is difficult to measure their extent, recognition of their existence will improve the ability of managers and citizens to evaluate the alternative.

Deciding what constitutes the "best" alternative is obviously not easy. Information on the issues identified above should clarify the costs and benefits associated with each alternative. In addition, public participation plays an important role in selecting a final alternative. Public participation

ensures that important issues in the area have been identified and dealt with. Because the LAC focuses on conditions, and because the costs and benefits associated with achieving the different alternatives have been identified, public groups will be able to focus their comments on specific assumptions, actions, or areas in the alternatives. It will also enable different groups to better understand how different alternatives affect their own interests.

In summary, step 8 involves the following:

PURPOSE

- To finalize opportunity class allocations and a specific management program to achieve this allocation

PROCESS

- Analyze resource, social, and managerial costs—what are they, who pays, what alternatives exist, etc.
- Analyze resource and social benefits—what are they, who receives them, etc.

PRODUCT

- Final allocation of opportunity classes and selection of a management program

STEP 9: IMPLEMENT ACTIONS AND MONITOR CONDITIONS

With selection of an alternative and its associated management program, the program must be implemented and its performance assessed. Monitoring provides systematic feedback on how well management actions are working and identifies trends in condition that require new actions. This is not a new step. Rather, it consists of periodically reassessing existing conditions (the inventory process described in step 4) and describing the difference between those conditions and the standards.

A major concern with monitoring is how frequent it should be. Ideally, all indicators addressed by standards would be frequently monitored areawide. Given budgetary constraints, however, certain indicators will be monitored less frequently than others and certain areas will be less closely monitored than others.

Generally, priorities for monitoring should consider situations where: (1) conditions were very close to standards at the time of the last assessment, (2) rates of resource or social change are judged to be the highest, (3) the quality of the data base is poorest, (4) the understanding of management action effects is poorest, or (5) there have been unanticipated changes in factors such as access, adjacent land uses, etc.

The results of monitoring will help evaluate program effectiveness and improve future programs. If monitoring shows that conditions remain better than standards, then current actions can be maintained until monitoring shows that standards will likely be exceeded. If monitoring shows that previously acceptable conditions have deteriorated and now exceed standards, then new actions are called for. If conditions had previously exceeded standards and monitoring shows they still do so, then the actions can be judged ineffective, at least within the time since initiated.

An action might prove ineffective for various reasons. Perhaps the action was appropriate, but its implementation was not effective or the programs have not had enough time to work. Trends reflected in the monitoring data should indicate where the problem lies. Monitoring should yield feedback regarding the value of certain management actions in solving particular kinds of problems. For example, use rationing might have been

prescribed to solve a problem of too many sites impacted by camping. If monitoring shows no decrease in the number of sites, very likely the problem and its causes have not been adequately defined. On the other hand, if conditions are improving, then perhaps the action just needs more time. The next round of monitoring will tell.

Managers need to be alert to changes in external circumstances that could affect the resource and social conditions within the wilderness. This would include such things as external access systems, adjacent land uses, population growth, or the relative availability of alternative types of recreational opportunities. In some cases, impacts stemming from such alterations can be coped with through different management actions. In the case of major changes, fundamental alterations in area management objectives might need to be considered. In summary, step 9 involves the following:

PURPOSE

- To implement a management program to achieve the objectives of the selected alternative
- To provide periodic, systematic feedback regarding the performance of the management program

PROCESS

- Periodically reinventory condition of indicators—essentially a repeat of step 4
- Compare indicator conditions with standards (repeat of step 8, but only for the final alternative)
- Analyze performance of management program

PRODUCT

- Summary of relationship between existing conditions and standards for all indicators in all opportunity classes
- Where necessary, recommendations of needed changes in management program in order to obtain satisfactory progress toward bringing existing conditions up to standards

ESTABLISHING USE LIMITS

Direct restriction of use numbers is an important and legitimate management action that will need to be employed at times in some areas in order to achieve certain conditions. The obvious question confronting managers, however, is how and where can use limits be established in a defensible and meaningful way?

If conditions under current use are well within established standards, it is difficult to project how much more use could be accommodated before the rising level of impact reached the standards. This is simply because our understanding of the relationship between use and impact is so poor. Not only would any such number be close to meaningless, but also the very existence of a figure purported to represent the capacity could contribute to a false sense of security that, as long as present use was below it, everything was all right. Moreover, when conditions are well within standards, there is no pressing need to formulate a specific numerical capacity. All that needs to be said is that capacity is greater than current use (Washburne 1982).

If existing conditions are close to, or have reached, one or more of the standards, we are alerted to a need to undertake some kind of management action. Usually some action other than a limit on use numbers will suffice, such as increased efforts to get visitors to practice minimum im-

pact camping. If other actions will not suffice, however, or if the standards have been exceeded by a wide margin, then use limits need to be imposed.

If existing conditions are close to those described in the area standards, then managers reasonably can assume that current use levels approximate capacity: the numerical capacity would be set at a level close to the current use level. Monitoring will help demonstrate if this assumption was valid. If conditions worsen, then that use level must be reduced.

In reducing use, managers should examine the specific indicators for which standards have been exceeded. This should help determine the level of the reduction. Ultimately, however, this will be a trial-and-error process. If daily trail encounters are twice the standard, managers might initially reduce use to half its present level. Monitoring will help fine-tune the needed use level.

Discussion of the LAC process has focused largely on its technical details. It is important, however, to recognize that the process takes place in a political environment in which different interests with different views and values seek to achieve the goals important to them. Planning is inherently a political process. Although the LAC process and the associated data are important aspects of the planning effort, they are only a part, and planners will need to use sensitivity and judgment to make the process successful.

Success is also tied to continued public participation. There is much expertise among public groups, and at each step in the process planners should seek to involve the public, both as a way of obtaining important information and as a way of developing support for and understanding of the process. Such participation can occur in a variety of ways, including meetings, workshops, and task forces. Ultimately, the specific technique for securing participation is less important than the recognition that such participation is important and necessary.

AN APPLICATION OF THE PLANNING PROCESS

The following example provides a step-by-step illustration of the LAC process. The process is applied to a hypothetical area, the Imagination Peaks Wilderness, and focuses on the concepts, rather than the specifics, of a real wilderness. We have incorporated characteristics of several real areas into the example, however, to keep it realistic and challenging.

Step 1: Identify Area Issues and Concerns

A background description of Imagination Peaks Wilderness includes area issues and concerns identified by managers and various public groups.

Imagination Peaks Wilderness is well known regionally, but less so nationally. It is one of eight wildernesses in the region, two of which are less than 100 miles away. One of the close wildernesses is smaller, used mainly by summer hikers. The other nearby wilderness is larger, but has fewer lakes and is more lightly used, with moderate hunting and horse use. The wilderness is medium sized (75,000 acres [30 000 ha]), and receives a fair amount of use. Last year, reports showed 50,000 RVD's (12-hour recreation visitor-days), largely due to visitors from a medium-sized town (35,000 population) as well as a college town (85,000) within an hour's drive of Imagination Peaks. One large city (200,000) is located about a 4-hour drive away. In the summer, recreational use is concentrated on the western end, which receives about 70 percent of visitor use, 80 percent of it by hikers.

During the fall, the concentration of use shifts northeast, with increasing use by hunters pursuing the fairly large elk herd. About half of the fall visitors use horses.

The summer use concentration on the western side is primarily the result of scattered lakes, most containing trout. Two lakes offer good fishing for California golden trout, a nonnative species introduced in the late 1940's. Compounding the problem of concentrated use are the easy access routes to these two lakes. Cliff Lake is only 2 miles (3 km) from the trailhead, and Granite Lake is 4 miles (6 km). A primary reason for low use on the eastern side appears to be more the lack of lakes and long, arduous distances rather than less scenic beauty.

Imagination Peaks has three legally licensed outfitters that use horses. They serve summer visitors, but operate mainly in the fall. There has been some illegal outfitter use in the northeastern portion of the wilderness. Two valleys on the eastern side are critical habitat for the endangered russet-toed ferret and a threatened plant, the furtive phlox, neither of which are found elsewhere in the region.

Imagination Peaks has a history of fire, with the first documented fires sweeping through in the 1830's. Intensive fire suppression measures began about 1920. A new fire management plan calls for fire resuming its role as an important natural ecological process. Mainly as a result of past fire suppression activities, the wilderness is extensively trailed, but some valleys and a few lake basins lack trails and are in essentially pristine condition. Keeping these lakes and their settings pristine is a concern of managers and some of the public.

The wilderness has low mineral potential and future mining is unlikely. However, commercial grazing exists, with two allotments for sheep totaling about 2,000 AUM's (animal unit months). Some wildlife competition occurs and there appears to be some conflict between visitors and sheep. Logging outside the wilderness is scheduled near the eastern boundary. The wilderness managers are concerned about the potential for easier access.

Public input has identified increasing use and crowding as a problem, especially in the westside lake basins. Some of the public feel that persons with a "purist" concept of wilderness are being displaced by the growing use. Management historically has been lighthanded and indirect in dealing with use problems because of concerns with more regulatory techniques.

Step 2: Define and Describe Opportunity Classes

Although four opportunity classes have been used in many other areas, only three were selected in the Imagination Peaks. This was because the area is not particularly large or unusually diverse, and public input suggested that four classes was confusing.

The three classes were named "semiprimitive," "primitive," and "pristine." The primitive and pristine are subclasses of the ROS primitive class.

Choosing class names was a struggle; the final choice fully satisfied no one. Names for wilderness opportunity classes can carry heavy connotations. Thus, some people felt "semiprimitive" sounded like watered-down wilderness (even though the ROS system clearly puts much wilderness in this class). "Pristine" sounded like an advertisement and some feared it would attract use.

A description of the resource, social, and managerial conditions for each class was developed:

1. The "semiprimitive" class will include those popular recreation areas with well-used trail systems to major destinations, usually lakes. Fairly numerous campsites, including a few that are substantially impacted, can be expected to be seen around lakes. Opportunities for solitude will be moderate; interparty contacts will be relatively high much of the time, both on the trails and at campsites. Some parties will camp out of sight and sound of other parties, but this will not be common during the main use season. Challenge will be low to moderate. Management presence will be higher than in other classes, with some regulations for visitor behavior, and both offsite and onsite management strategies will be employed.

2. The "primitive" class will provide good opportunities for solitude and evidence of recreational use will be only moderately numerous and apparent. Modest numbers of campsites with intermediate degrees of impact will be expected. Visitor contacts on the trail will be moderate, and contacts at the campsite will be fairly low, with parties often camped in isolation. Challenge will be moderate. Management presence will be felt mainly through indirect channels, but personnel will be present onsite at times.

3. The "pristine" class is at the far end of the spectrum from the semiprimitive class. It is not visitor oriented and places high priority on the protection of the wilderness resource. Campsites will be few in number, widely separated, and will be so little impacted that most will recover within 1 year. Outstanding opportunities for solitude are provided. Interparty contacts will be very few while traveling, and rare to nonexistent at the campsite. Challenge will be high. There is very little management presence. Offsite education and access modification will be the main visitor management opportunity with an absolute minimum of regulations. Most of the class is trailless.

Step 3: Select Indicators of Resource and Social Conditions

After the establishment of three opportunity classes, factors of resource and social conditions were selected to describe the classes more precisely; then for each factor, one or more indicators were chosen (see the following tabulation). Indicators were purposely oriented toward those which could be quantified such as multiple trails, degree of forage utilization, and number of encounters with other recreationists. For six factors, nine indicators that were important for the preservation of Imagination Peaks Wilderness were identified. It is recognized that better indicators may evolve later through monitoring.

Factors and Indicators Considered for the Imagination Peaks Wilderness

Factor	Indicator
SOCIAL	
A. Solitude while traveling	1. Number of other parties met per day while traveling
B. Campsite solitude	2. Number of other parties camped within sight or sound per day
RESOURCE	
C. Trail conditions	3. Percent of trail system miles (km) with multiple trails
	4. Percent of trail system miles (km) with severe erosion (entrenchment of over 4 ft^2 [1.3 m^2] cross-section) and/or very muddy, boggy areas 10 ft (3 m) or longer
D. Campsite conditions	5. Number of campsites per 500-acre (200-ha) area (a circle 1 mile [1.6 km] in diameter)
	6. Square feet (m^2) of devegetated area within any 5-acre (2-ha) circle
	7. Condition class rating (a composite rating based on the severity of a number of impacts on the campsite, with class 1 very minimally impacted and class 5 severely impacted (Cole 1983; Frissell 1978)
E. Range conditions	8. Degree of forage utilization
F. Threatened and endangered species	9. Population trend for threatened and endangered species (associated with probable human causes)

These factors and indicators relate logically to the descriptions of each opportunity class and are consistent with the issues and concerns identified, as well as with the Wilderness Act and agency policy.

To keep the example simple and brief, just one social factor—campsite solitude—and its indicator and one resource factor—campsite conditions—and its three indicators will be discussed.

These two factors were chosen because of their importance. Research has shown campsite solitude to be particularly significant to wilderness visitors (Stankey 1973). Visitors express a strong preference for few other campers nearby, usually preferring none at all. Thus the indicator chosen refers to numbers of other camper groups in the vicinity of which campers would be aware. It is relevant in the Imagination Peaks because camper use, especially at many of the westside lakes, is often heavy, and was an issue identified by both managers and visitors.

Campsites are the main area where recreation impacts to the environment occur (most trail impacts result from construction). Campsites can proliferate greatly. They are usually in key locations near attractions where they are conspicuous to visitors. Visitors spend much of their time

at campsites, so a large part of their experience can be influenced by campsite conditions.

The three indicators address the major aspects of campsite impacts: (1) The density of campsites indicates the number and concentration of campsites—the extent of proliferation of impacts, in effect, as seen from the air. (It also reflects opportunities for campsite solitude, of course.) The 500-acre (200-ha) frame of reference was chosen as a reasonable-sized area to be concerned with at one time. This would be about a 1-mile (1.6-km) diameter circle, which is about the size of typical lake basin destination areas in the Imagination Peaks. Campsites could be mapped and density checked by sliding a clear overlay with a 500-acre (200-ha) circle on it over the map, counting the largest number of campsites that can be enclosed in the circle. (Whenever the number of campsites changes, the new number is recorded. This means the same campsite may be counted more than once because the circles may overlap.) (2) Size of devegetated area indicates amount of area showing the most common type of recreational impact, as seen by a person walking into the campsite or through a cluster of closely spaced or coalescing campsites within a 5-acre (2-ha) block. The indicator could have referred to individual campsites, but often sites are not separate and distinct, and a concern for cumulative effects in a localized area led to choice of a 5-acre (2-ha) circle as a frame of reference. A 5-acre (2-ha) circle is about 530 feet (about 165 m) in diameter. (3) Condition class rating indicates severity of a variety of impacts—exposed roots, damaged trees, bare soil exposure, and nonnative plant invaders.

All three indicators are concerns in the Imagination Peaks. Some of the popular lakes have large numbers of campsites around them. There, and especially in some of the hunting camps, large core areas have lost almost all vegetation. Some popular locations have numerous clustered campsites with substantial aggregate impacts. Some campsites, both some of the large ones and a few of the smaller ones, have severe impacts such as felled trees and exposed roots.

Step 4: Inventory Existing Resource and Social Conditions

To inventory the existing conditions in Imagination Peaks, wilderness rangers were given tally sheets to keep track of the nine indicators chosen. All areas of the wilderness were covered. Particularly for the social indicators, attention was directed toward obtaining encounter figures during peak and low periods to obtain the full range of occurrences. Location and condition of campsites and encounters at the campsite were mapped in the office after the use season was completed. The map (fig. 7) shows the location, devegetated area, and condition class of campsites identified for one of the popular lakes, Cliff Lake.

The Cliff Lake campsite map shows a large number of campsites (20) and high concentrations on the two points. The south and east sides of the lake have more campsites than does the west side, although the condition on these two sides of the lake does not appear to be too bad, except on the two points. There are no class 5 highly impacted sites, but only one class 1 very lightly impacted site.

Campsite density at Cliff Lake, as recorded by counting campsites located inside a sliding 500-acre (200-ha) circle, is shown below:

Number of campsites in 500-acre (200-ha) circle = 20
Number of times tallied = 1

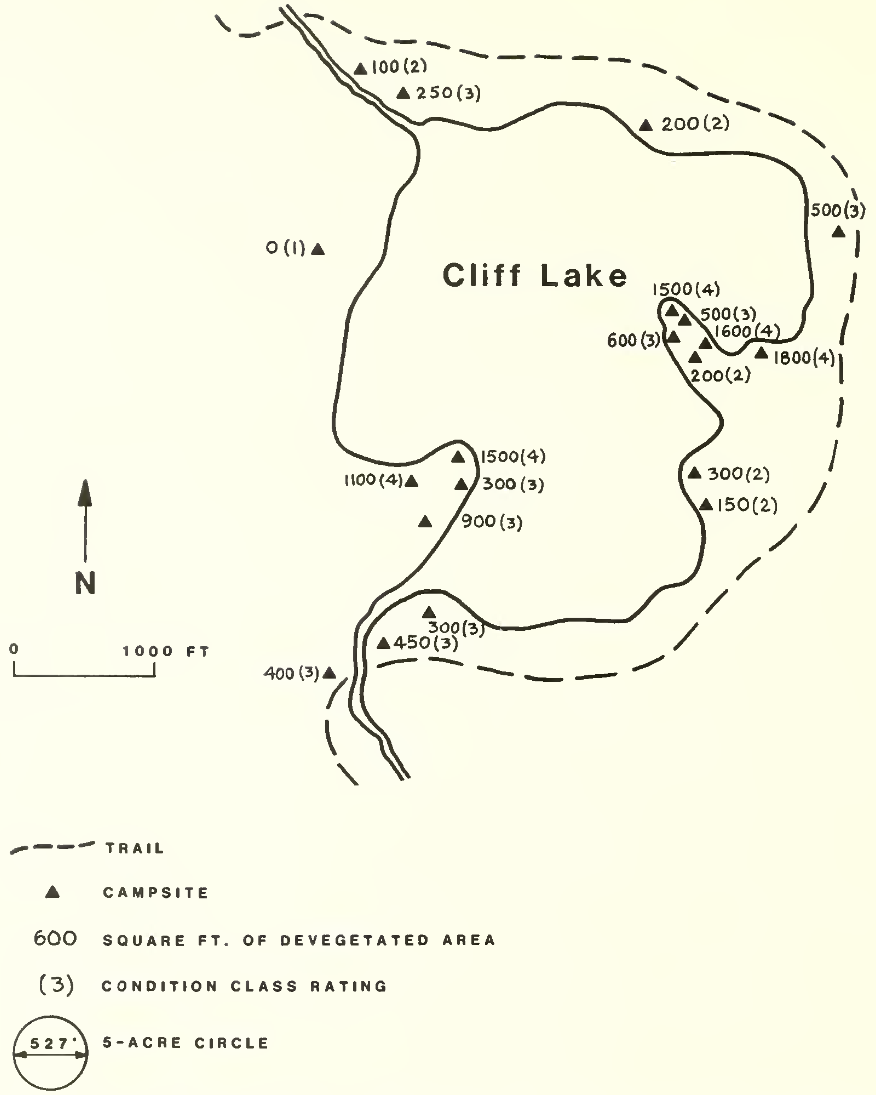


Figure 7.—Campsite distribution, devegetated area, and condition class ratings for Cliff Lake, Imagination Peaks Wilderness.

The number of campsites in different condition classes in the Cliff Lake area were tallied as follows:

Campsite class condition	Number of times tallied
1	1
2	5
3	9
4	5
5	0

Total devegetated area was measured within 5-acre (2-ha) circles in the office, working with the data recorded on the map.The tally was as follows:

Total devegetated area within a 5-acre (2-ha) circle	**Number of times tallied**
0	1
200	1
350	1
450	1
500	1
750	1
950	1
3,600 (3 sites on base of the western point)	1
3,800 (4 sites on the southeastern point)	1
4,400 (5 sites on tip of the western point)	1

As the 5-acre (2-ha) circle was slid across the map, a tally was recorded every time a different group of campsites was enclosed. This meant that some campsites in close clusters fell in several groups, and their devegetated area added to the total of several tallies. This happened on the western point for example. (The same inclusion of a campsite in more than one tally can happen for campsite density.) For isolated campsites (at least 530 feet [165 m] from another campsite), such as the one on the eastern side of the lake, the results using the 5-acre (2-ha) circle are identical to a standard based on individual campsites.

Data on campsite encounters were also collected by the wilderness rangers. Because of terrain and forest cover, some of the campsites are screened from others. The groupings of campsites within which campers would be aware of other campers were identified in the field and mapped, as shown on figure 8. There are six groupings, some of which overlap, as also occurred with the sliding circles. Within each grouping, the total number of occupied camps that each of the camper groups would be aware of was tallied, as shown in figure 8. (This number is equal to the total number of occupied campsites in the grouping minus one, because each party encounters all the other parties, except their own.) These were the numbers recorded in the wilderness rangers' notebooks on each of the six occasions when they observed Cliff Lake in the evening or early morning when most campers were present. Six checks for six groupings produced a total of 36 observations. Average numbers of camp encounters for each of the six campsites groupings, based on the six checks, are also shown. The results were tallied thus:

Daily tallies of campsite encounters per campsite grouping		
Number of encounters	Number of times tallied	Percent of tallies
0	19	53
1	10	28
2	3	8
3	3	8
4	0	0
5	1	3
Total	36	100

Average number of encounters per campsite grouping for all observations during the season	
Average number	Number of occurrences
0	1
0.1-1.0	3
1.1-2.0	1
2.1-3.0	1
Total	6

A similar tally of camping encounters was done for other locations.

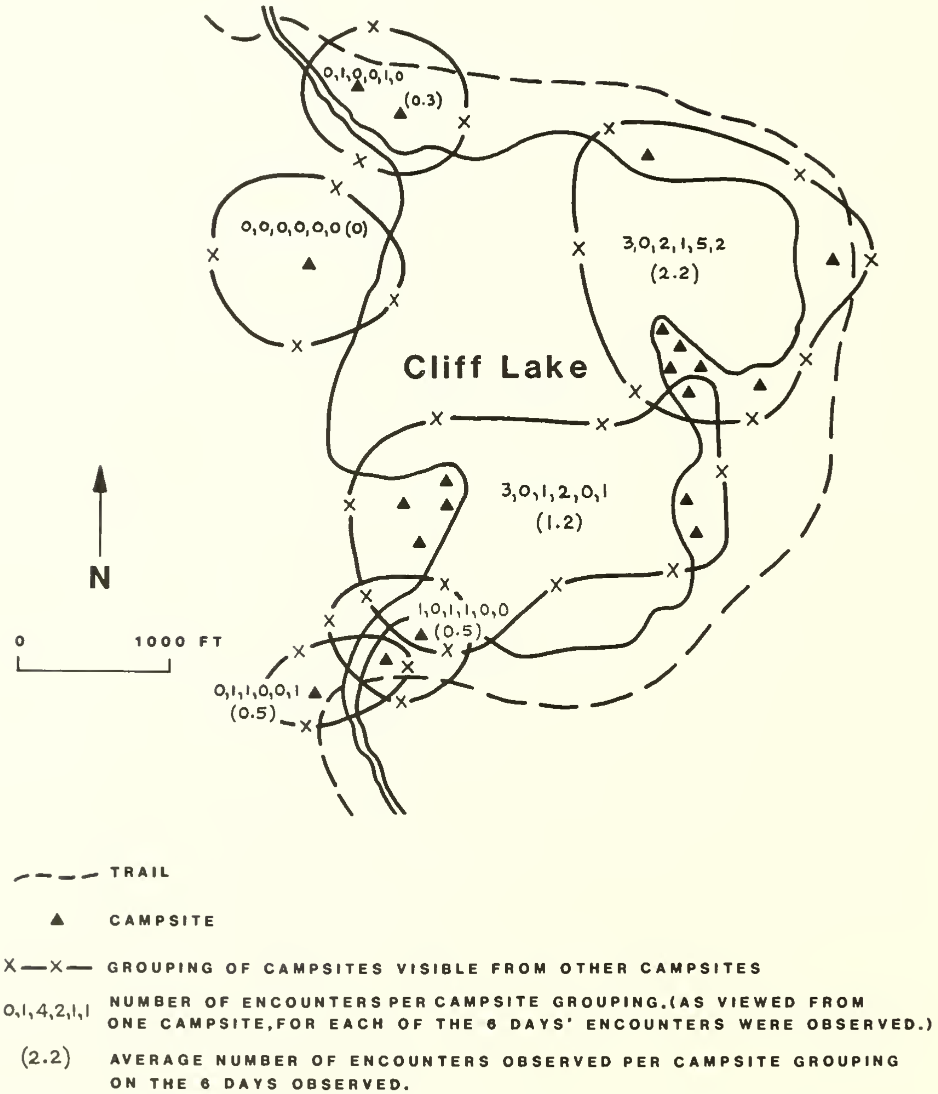


Figure 8.—Numbers of visitor encounters at campsites, Cliff Lake, Imagination Peaks Wilderness.

Step 5: Specify Standards for Resource and Social Indicators for Each Opportunity Class

Inventorying conditions resulted in a few surprises for some of the managers. There were more campsites, especially on the western side of the Imagination Peaks Wilderness, than originally thought, but fewer were in poor condition than expected. Camp encounters in most areas were less than expected, but some camping areas had tallies of up to five encounters per night, and several areas averaged over two. With these points in mind, the managers drafted campsite encounter standards considered to uphold the quality of the wilderness while being attainable.

Opportunity class	Factor	Indicator	Standard
Semi-primitive	Campsite solitude	No. of camp encounters/ party/day	Two encounters or less per night for at least 90 percent of the tallies during the main use season
Primitive	Campsite solitude	No. of camp encounters/ party/day	One encounter or less per night for at least 90 percent of the tallies during the main use season
Pristine	Campsite solitude	No. of camp encounters/ party/day	No encounters for at least 90 percent of the tallies during the main use season

Standards were next developed for campsite conditions, as follows:

Opportunity class	Factor	Indicator	Standard
Semi-primitive	Campsite conditions	Camps per 500 acres (200 ha)	Not more than 15 sites in any 500 acres (200 ha)
		Devegetated area/5 acres (2 ha)	Not over 2,500 ft^2 (245 m^2)
		Condition class	No class 5 sites; not more than three class 4 sites in any 500 acres (200 ha)
Primitive	Campsite conditions	Camps per 500 acres (200 ha)	Not more than eight sites in any 500 acres (200 ha)
		Devegetated area/5 acres (2 ha)	Not over 1,000 ft^2 (100 m^2)
		Condition class	No class 5 sites; not more than one class 4 site in any 500 acres (200 ha)
Pristine	Campsite conditions	Camps per 500 acres (200 ha)	Not more than two campsites in any 500 acres (200 ha)
		Devegetated area/5 acres (2 ha)	Not over 200 ft^2 (19 m^2)
		Condition class	No class 4 or 5 sites; not more than one class 3 site in any 500 acres (200 ha)

Step 6: Identify Alternative Opportunity Class Allocations Reflecting Area Issues and Concerns and Existing Resource and Social Conditions

Two alternative allocations of opportunity classes were developed. One was oriented more toward wilderness recreational use, the other more toward resource preservation. The managers felt two alternatives adequately dealt with the area issues and concerns, and reflected existing conditions.

Managers decided to keep the management areas they had used in the past. It seemed to facilitate the conceptualization of the areas as specific opportunity classes and also helped managers deal with specialized management actions for problem areas. Management areas were defined mainly by topographic features and use patterns (fig. 9). Management areas 7, 8, and 9 represent the highest use areas in the Imagination Peaks. Area 4 represents the critical habitat for the furtive phlox and the russet-toed ferret. Areas 10, 1, 2, 3, and 4 represent the best elk habitat. Sheep grazing is confined to areas 5, 6, and 7.

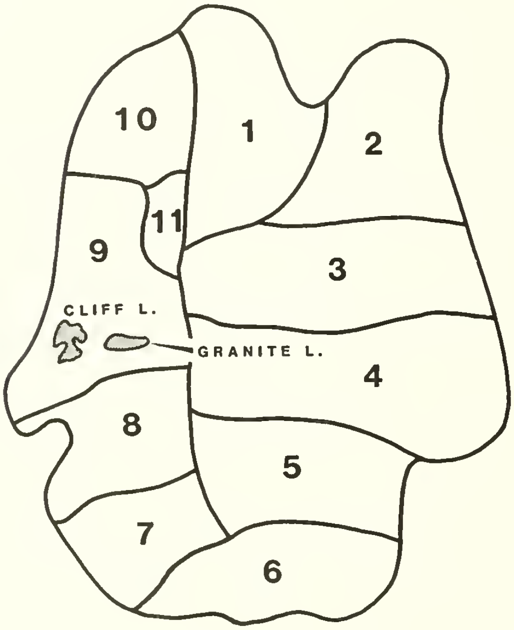


Figure 9.—Management areas delineated on the basis of landform and use patterns, Imagination Peaks Wilderness.

Figures 10 and 11 show the distribution of opportunity classes accordingly for each of the two alternatives. Figure 10 (which is oriented toward recreational uses) shows that management areas 1, 2, 7, 8, and 9 were categorized as semiprimitive areas, largely because of their existing use patterns and attractions (area 1 contains most elk hunter camps, with most of the remainder in 2). Areas 3, 5, 6, and 10 were categorized as primitive areas. Area 10 will present some difficulty because the use is higher than the standard for this class. Areas 5 and 6 may have some problems meeting the range utilization standard because of domestic sheep grazing. Management areas 4 and 11 were classified as pristine, area 4 primarily due to critical habitat for threatened and endangered species that cannot tolerate much use, and area 11 because of several trailless, seldom visited lakes.

Figure 11 reflects an ecological preservation orientation and as such incorporates most of the eastern portion (areas 3, 4, and 5) plus area 10 into the pristine class. Management areas 2 and 7 are shifted to the primitive category. This is feasible but will require intensive management. Areas 8 and 9 are left as semiprimitive, because they offer no unique or excessively fragile habitats and are popular attraction sites for visitors.

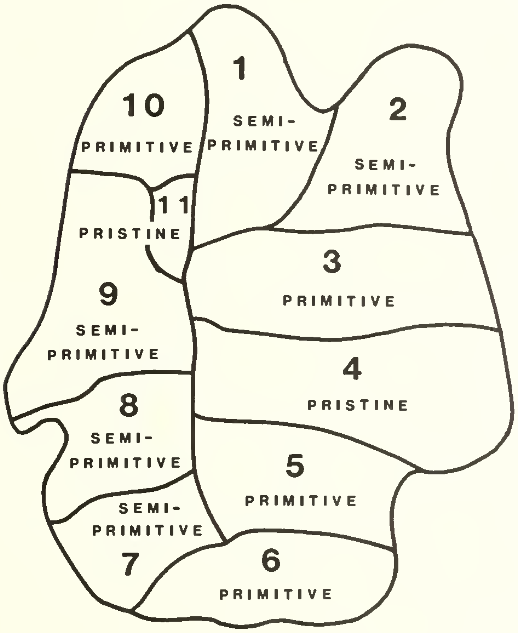


Figure 10.—Recreationally oriented opportunity classification, Imagination Peaks Wilderness.

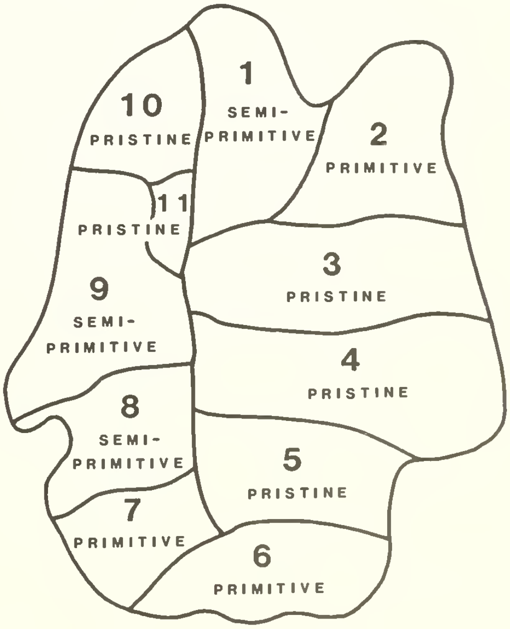


Figure 11.—Ecologically oriented opportunity classification, Imagination Peaks Wilderness.

Step 7: Identify Management Actions for Each Alternative

In order to identify the management actions in depth for each alternative, it seemed clearer to show how two management areas fared under both alternatives. Following is a discussion of the proposed management actions for management areas 3 and 9.

A major problem in management area 9 (semiprimitive class under both alternatives) is the large number of campsites, many of which are substantially impacted. A number of alternative management actions might be taken to mitigate this problem, including reducing use, minimum impact education, site closure, and relocation of camping to more durable locations. Specific actions selected are to:

1. Only allow campfires at certain designated sites distributed so that no more than one such site is located in any 5 acres (2 ha).
2. Permanently close and rehabilitate about half of the more impacted campsites so that no 500-acre (200-ha) area has more than 15 sites, and aggregate devegetated area in campsite clusters does not exceed 2,500 ft^2 (245 m^2).
3. At the two most popular lakes, encourage some camping to shift to durable benches above the lakes, which also offer spectacular views.
4. Intensive minimum impact education campaigns will be incorporated into the next season using rangers, field offices, brochures, and workshops for special target groups.
5. Increase management presence onsite to encourage no new campsite development except on the benches.
6. The popular golden trout which reproduce poorly will not be restocked, and future stocking will be with native cutthroat trout. This will result in a more natural ecosystem and probably some reduction in visits.

Such a program is preferable to either rationing use, which restricts recreational opportunities and may not correct the campsite impact problem, or heavy-handed regulations that completely eliminate opportunities for having campfires. This is consistent with the objectives of providing opportunities for recreational use of lake basins and minimizing management obtrusiveness.

To reduce the number of campsite encounters so the standard is not violated, either total use in the area must be reduced or visitors within the area must be more widely distributed. The situation is complicated by the existence of two trailless lakes in adjacent area 11 which managers want to keep in a pristine condition. Consequently, distributing use within the management area is undesirable. Some increased dispersal will occur as a result of the campsite policies just outlined. The decision in this case is to encourage dispersal to management areas 7 and 8 where increased use appears unlikely to violate standards. However, monitoring of the consequences of these altered use patterns will be crucial.

Under the more recreation-oriented alternative, area 3 is in the primitive class. It has two outfitter hunting camps off the only trail in the area and half a dozen other campsites. All standards are currently met, although some by only a narrow margin. Management actions would be (1) build no new trails; (2) after logging nearby (outside the wilderness) is completed, close the roads to vehicle traffic to avoid easier access; (3) stress minimum impact camping education, targeting hunters and horsemen; (4) attempt to eliminate illegal outfitter operations.

Under the ecological orientation alternative, the management action would not vary for area 9, which is still classified semiprimitive. This is not the case for management area 3. In the ecological orientation, area 3 becomes pristine. Several standards are presently exceeded. The more intensive management actions for this alternative include (1) termination of permits for outfitter camps (move them to area 2); (2) closure of one class 4 site and one class 3 where there now are three sites in a 500-acre (200-ha) area, leaving just one class 2 site; (3) reduce maintenance of the one trail and develop a new spur trail in area 2 to provide an attractive alternative; and (4) intensify minimum camping education.

Step 8: Evaluation and Selection of a Preferred Alternative

Evaluation and selection of the preferred alternative resulted in the development and choice of a modified version of the recreational alternative. The high costs associated with reducing use necessary to achieve the ecologically oriented alternative in the Imagination Peaks were felt to be excessive and not in the public's best interest. Other wildernesses in the region appear to be more appropriate for an emphasis on ecological preservation. From public involvement, area 10 was converted to the pristine class to further the goal of keeping some lake basins very natural. This northwestern corner is quite isolated, has poor access, and current light use. There was a strong public reaction against removing the California golden trout, as fishing is one of the popular reasons for visiting Imagination Peaks, and the golden trout has received a lot of publicity. Despite this, managers recommend gradual replacement of exotic species with native species in more remote Granite Lake, and continued efforts to educate the public on the reasons this action should be taken later in Cliff Lake.

Step 9: Implement Actions and Monitor Conditions

Beginning with the next field season, actions will be implemented. In our example, management areas 7, 8, and 9 will receive high priority because of their associated problems. A monitoring program will also be implemented. Every 3 years in the more heavily used and impacted areas existing conditions will be systematically monitored and compared to the standards. This will be done every 5 years in the more remote and lightly used areas where problems are currently minor. Wilderness rangers will be responsible for this task in addition to periodic checking to suggest whether full-scale monitoring should be done sooner than planned in response to problems. Some conditions that can be monitored easily in the course of performing regular duties, such as recording newly developed campsites and observing numbers of campsites occupied within sight of one another, will be checked continuously. Because the standards have been chosen with the best knowledge we have, but may not necessarily be the best for the situation, managers will retain the flexibility to modify them as the monitoring of conditions and apparent effectiveness of management actions seem to indicate.

SUMMARY

The LAC process emphasizes explicit statements of objectives. Diversity in resource and social conditions is promoted by the definition of three different opportunity classes. Field conditions are examined to determine standards that are feasible but that will protect wilderness conditions. Management actions can then be designed to bring conditions back to their desired state or assure that they stay in the desired state, for each of several alternative allocations to opportunity classes. An alternative is chosen and implemented. Monitoring provides the feedback necessary to periodically modify management actions or, in some cases, standards or objectives. The public is involved throughout the process.

The preceding example illustrates the flexibility of the LAC process. Many alternative courses of action are open to the wilderness manager. Limiting numbers of users to a carrying capacity is just one possible solution. Choosing the best management approach involves judgment and is dependent upon good information—about desired conditions, current conditions, and the consequences of alternative management actions. Attention is focused on critical problems at specific locations. By working through the process, managers should be able to avoid restricting and regulating visitors except when and where truly necessary.

REFERENCES

Absher, James D.; Lee, Robert G. Density as an incomplete cause of crowding in backcountry settings. Leisure Sciences. 4: 231-248; 1981.

Barton, Michael A. Water pollution in remote recreational areas. Journal of Soil and Water Conservation. 24: 132-134; 1969.

Bratton, Susan Power; Hickler, Matthew G.; Graves, James H. Visitor impact on backcountry sites in Great Smoky Mountains. Environmental Management. 2: 431-442; 1978.

Buist, Leon J.; Hoots, Thomas A. Recreation opportunity spectrum approach to resource planning. Journal of Forestry. 80: 84-86; 1982.

Bultena, Gordon; Albrecht, Donald; Womble, Peter. Freedom versus control: a study of backpackers' preferences for wilderness management. Leisure Sciences. 4: 297-310; 1981.

Clark, Roger N. Promises and pitfalls of the ROS in resource management. Australian Parks and Recreation. May 1982: 9-13.

Clark, Roger N.; Stankey, George H. The recreation opportunity spectrum: a framework for planning, management, and research. General Technical Report PNW-98. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1979a. 32 p.

Clark, Roger N.; Stankey, George H. Determining the acceptability of recreational impacts: an application of the outdoor recreation opportunity spectrum. In: Ittner, R.; Potter, D. R.; Agee, J. K.; Anschell, S., eds. Recreational impact on wildlands. R-6-001-1979. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region; 1979b: 32-42.

Cole, David N. Monitoring the condition of wilderness campsites. Research Paper INT-302. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1983. 10 p.

Cole, David N. Wilderness campsite impacts: effect of amount of use. Research Paper INT-284. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1982. 34 p.

Cole, David N. Managing ecological impacts at wilderness campsites: an evaluation of techniques. Journal of Forestry. 79: 86-89; 1981.

Cole, David N.; Dalle-Molle, John. Managing campfire impacts in the backcountry. General Technical Report INT-135. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1982. 16 p.

Cole, David N.; Schreiner, Edward G. S. Impacts of backcountry recreation: site management and rehabilitation—an annotated bibliography. General Technical Report INT-121. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1981. 58 p.

Dailey, Tom; Redman, Dave. Guidelines for roadless area campsite spacing to minimize impact of human-related noises. General Technical Report PNW-35. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1975. 20 p.

Dale, D.; Weaver, T. Trampling effects on vegetation of the trail corridors of north Rocky Mountain forests. Journal of Applied Ecology. 11: 767-772; 1974.

Driver, Beverly L.; Brown, Perry J. The opportunity spectrum concept and behavioral information in outdoor recreation resource supply inventories: a rationale. In: Lund, G. H.; LaBau, V. J.; Ffolliott, P. F.; Robinson, D. W., tech. coords. Integrated inventories of renewable natural resources. General Technical Report RM-55. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station; 1978: 24-31.

Federal Register. Rules and regulations: national forest system and resource management planning; 47: 7690; 1982.

Frissell, Sidney S. Judging recreation impacts on wilderness campsites. Journal of Forestry. 76: 481-483; 1978.

Frissell, Sidney S.; Lee, Robert G.; Stankey, George H.; Zube, Ervin H. A framework for estimating the consequences of alternative carrying capacity levels in Yosemite Valley. Landscape Planning. 7: 151-170; 1980.

Frissell, Sidney S.; Stankey, George H. Wilderness environmental quality: search for social and ecological harmony. Proceedings of the Society of American Foresters. 1972: 170-183.

Godin, Victor B.; Leonard, Raymond E. Design capacity for backcountry recreation management planning. Journal of Soil and Water Conservation. 32: 161-164; 1977.

Harrison, Robin T.; Clark, Roger N.; Stankey, George H. Predicting impact of noise on recreationists. ED&T Project No. 2688. San Dimas, CA: U.S. Department of Agriculture, Forest Service, San Dimas Equipment Development Center; 1980. 32 p.

Helgath, Sheila F. Trail deterioration in the Selway-Bitterroot Wilderness. Research Note INT-193. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1975. 15 p.

Hendee, John C.; Clark, Roger N.; Hogans, Mack L.; Wood, Dan; Koch, Russell W. Code-A-Site: a system for inventory of dispersed recreational sites in roaded areas, backcountry, and wilderness. Research Paper PNW-209. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1976. 33 p.

Hendee, John C.; Stankey, George H.; Lucas, Robert C. Wilderness management. Miscellaneous Publication No. 1365. Washington, DC: U.S. Department of Agriculture, Forest Service; 1978. 381 p.

King, John. The effects of recreational use on water quality in the vicinity of campsites in the Boundary Waters Canoe Area. St. Paul, MN: University of Minnesota; 1971. 125 p. M.S. thesis.

Lee, Robert G. Alone with others: the paradox of privacy in wilderness. Leisure Sciences. 1: 3-20; 1977.

Leonard, R.E.; Echelberger, H. E.; Plumley, H. J.; VanMeter, L. W. Management guidelines for monitoring use on backcountry trails. Research Note NE-286. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station; 1980. 20 p.

Leonard, R. E.; Plumley, H. J. Human waste disposal in eastern backcountry. Journal of Forestry. 77: 349-352; 1979.

Leonard, R. E.; Whitney, A. M. Trail transect: a method for documenting trail changes. Research Paper NE-389. Upper Darby, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station; 1977. 8 p.

Lime, David W. Research for determining use capacities of the Boundary Waters Canoe Area. Naturalist. 21: 8-13; 1970.

Lucas, Robert C. Recreation regulations—when are they needed? Journal of Forestry. 80: 148-151; 1982.

McFeters, Gordon A. Microbial studies of a high alpine water supply used for recreation. Bozeman, MT: Montana State University; 1975. 12 p. Final report to the National Park Service.

Neil, P. H.; Hoffman, R. W.; Gill, R. B. Effects of harassment on wild animals—an annotated bibliography of selected references. Denver, CO: Colorado State Division of Wildlife; 1975. 21 p.

Parsons, David J.; MacLeod, Susan A. Measuring impacts of wilderness use. Parks. 5: 8-12; 1980.

Petersen, Margaret E. Trends in recreational use of National Forest wilderness. Research Note INT-319. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1981. 3 p.

Ream, Catherine H. Impacts of backcountry recreationists on wildlife: an annotated bibliography. General Technical Report INT-81. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1980. 62 p.

Ream, Catherine H. Human-wildlife conflicts in backcountry: possible solutions. In: Ittner, R.; Potter, D. R.; Agee, J. K.; Anschell, S., eds. Recreational impact on wildlands. R-6-001-1979. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region; 1979: 153-163.

Schreyer, Richard; Roggenbuck, Joseph W. The influence of experience expectations on crowding perceptions and social-psychological carrying capacities. Leisure Sciences. 1: 373-394; 1978.

Shechter, Mordechai; Lucas, Robert C. Simulation of recreational use for park and wilderness management. Johns Hopkins University Press; 1978. 220 p.

Shelby, Bo. Crowding models for backcountry recreation. Land Economics. 56: 43-55; 1980.

Silverman, G.; Erman, D. C. Alpine lakes in Kings Canyon National Park, California: baseline conditions and possible effects of visitor use. Journal of Environmental Management. 8: 73-87; 1979.

Stankey, George H. A comparison of carrying capacity perceptions among visitors to two wildernesses. Research Paper INT-242. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1980. 34 p.

Stankey, George H. Visitor perception of wilderness recreation carrying capacity. Research Paper INT-142. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1973. 34 p.

Stanley, J. T.; Harvey, H. T.; Hartesveldt, R. J. A report on the wilderness impact study. San Francisco, CA: The Sierra Club; 1979. 290 p.

Taylor, Timothy P.; Erman, Don C. The littoral bottom fauna of high elevation lakes in Kings Canyon National Park. California Fish and Game. 66: 112-119; 1980.

Taylor, T. P.; Erman, D. C. The response of benthic plants to past levels of human use in high mountain lakes in Kings Canyon National Park, California, U.S.A. Journal of Environmental Management. 9: 271-278; 1979.

Temple, Kenneth L.; Camper, Anne K.; Lucas, Robert C. Potential health hazard from human wastes in wilderness. Journal of Soil and Water Conservation. 37: 357-359; 1982.

Temple, Kenneth L.; Camper, Anne K.; McFeters, Gordon A. Survival of two enterobacteria in feces buried in soil under field conditions. Applied Environmental Microbiology. 40: 794-797; 1980.

U.S. Department of Agriculture, Forest Service. ROS users guide. Washington, DC: U.S. Department of Agriculture, Forest Service; n.d. 38 p.

van der Smissen, Betty. Indicators of change in the recreation environment—a national research symposium. Penn State HPER Series No. 6. State College, PA: Pennsylvania State University, College of Health, Physical Education and Recreation; 1975. 471 p.

Washburne, Randel F. Wilderness recreational carrying capacity: are numbers necessary? Journal of Forestry. 80: 726-728; 1982.

Washburne, Randel F.; Cole, David N. Problems and practices in wilderness management: a survey of managers. Research Paper INT-304. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1983. 56 p.

Weaver, T.; Dale, D. Trampling effects of hikers, motorcycles, and horses in meadows and forests. Journal of Applied Ecology. 15: 451-457; 1978.

West, Patrick C. On-site social surveys and the determination of social carrying capacity in wildland recreation management. Research Note NC-264. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station; 1981. 4 p.

*U.S. GOVERNMENT PRINTING OFFICE: 1984-0-576-040/10523

Stankey, George H.; Cole, David N.; Lucas, Robert C.; Petersen, Margaret E.; Frissell, Sidney S. The Limits of Acceptable Change (LAC) system for wilderness planning. General Technical Report INT-176. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1985. 37 p.

A wilderness management-by-objectives planning system is outlined. Through identification of standards, acceptable wilderness conditions are defined and appropriate management actions formulated. A case example is provided.

KEYWORDS: wilderness management, carrying capacity, wilderness planning, limits of acceptable change

The Intermountain Station, headquartered in Ogden, Utah, is one of eight regional experiment stations charged with providing scientific knowledge to help resource managers meet human needs and protect forest and range ecosystems.

The Intermountain Station includes the States of Montana, Idaho, Utah, Nevada, and western Wyoming. About 231 million acres, or 85 percent, of the land area in the Station territory are classified as forest and rangeland. These lands include grasslands, deserts, shrublands, alpine areas, and well-stocked forests. They supply fiber for forest industries; minerals for energy and industrial development; and water for domestic and industrial consumption. They also provide recreation opportunities for millions of visitors each year.

Field programs and research work units of the Station are maintained in:

Boise, Idaho

Bozeman, Montana (in cooperation with Montana State University)

Logan, Utah (in cooperation with Utah State University)

Missoula, Montana (in cooperation with the University of Montana)

Moscow, Idaho (in cooperation with the University of Idaho)

Provo, Utah (in cooperation with Brigham Young University)

Reno, Nevada (in cooperation with the University of Nevada)

FOREST SERVICE
U S
DEPARTMENT OF AGRICULTURE

United States
Department of
Agriculture

Forest Service

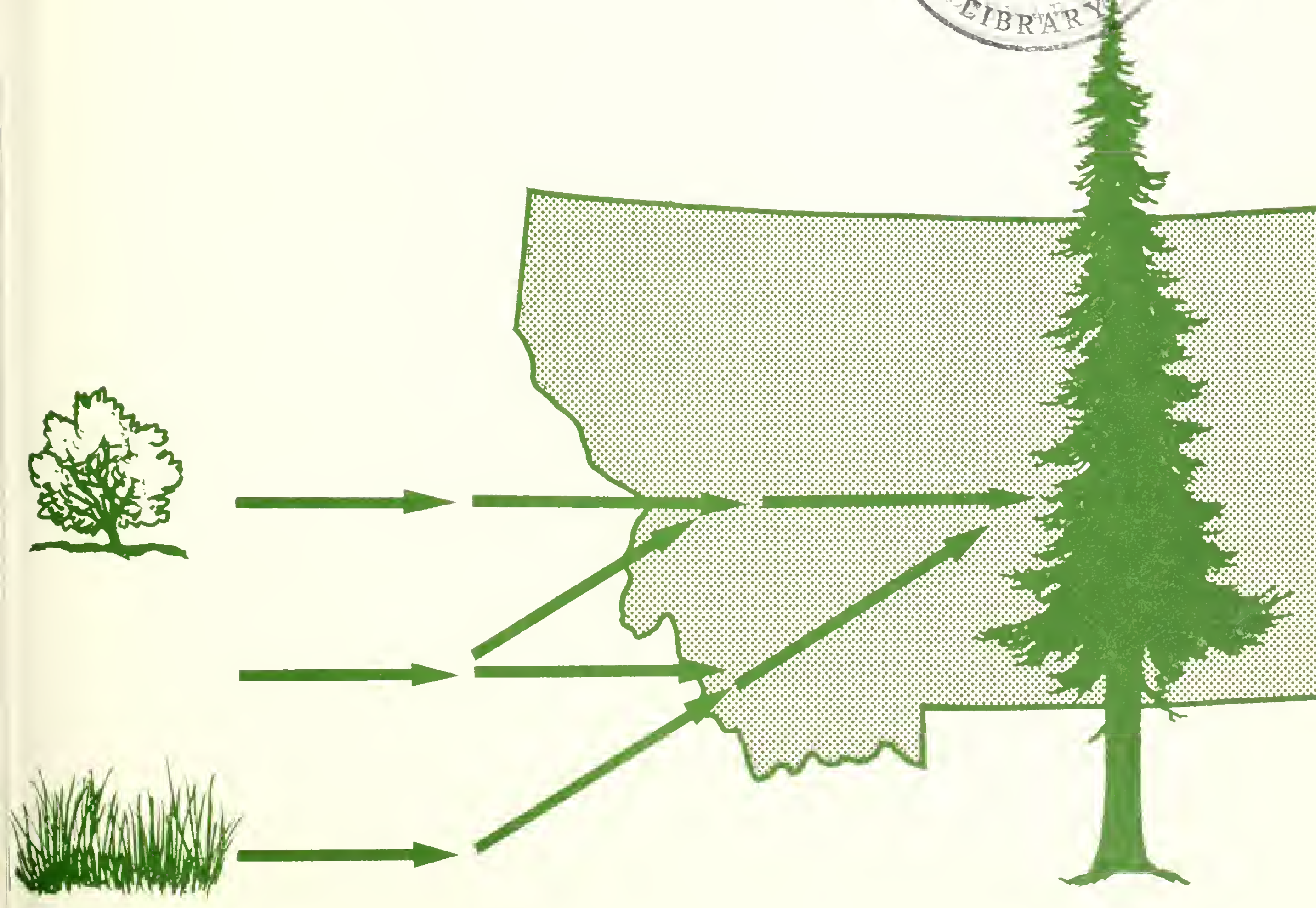
**Intermountain
Forest and Range
Experiment Station
Ogden, UT 84401**

General Technical
Report INT-177

March 1985

Forest Succession on Four Habitat Types in Western Montana

**Stephen F. Arno
Dennis G. Simmerman
Robert E. Keane**



THE AUTHORS

STEPHEN F. ARNO is a research forester in the Prescribed Fire and Fire Effects research work unit at the Northern Forest Fire Laboratory, Missoula, MT. He was a coauthor of the Montana forest habitat type classification (Pfister and others 1977) and has studied various aspects of forest ecology since joining the Forest Service in 1970.

DENNIS G. SIMMERMAN is a forester with the Prescribed Fire and Fire Effects research work unit located at the Northern Forest Fire Laboratory. Previously he worked with the Fire Technology research work unit. He earned a B.S. degree in forestry from the University of Arizona.

ROBERT E. KEANE conducted the field evaluation of the successional classification under a cooperative agreement between the Intermountain Forest and Range Experiment Station and the University of Montana. He is modeling the successional pathways using a computer as part of his M.S. degree program at the University's School of Forestry. He earned a B.S. degree from the University of Maine in forest engineering and later worked with ecological consulting firms.

ACKNOWLEDGMENTS

Robert Pfister (director of the Mission-Oriented Research Program at the University of Montana's forestry school) provided encouragement and valuable advice for developing and carrying out this study. Many others have also provided detailed suggestions that have led to improvement in this work. These include James K. Brown, Project Leader, Northern Forest Fire Laboratory, Missoula, MT; James R. Habeck, professor, Botany Department, University of Montana; Robert Steele and Russell A. Ryker, research foresters, Forestry Sciences Laboratory, Boise, ID; Stephen V. Cooper, forest ecologist, Forestry Sciences Laboratory, Missoula, MT; Kenneth Neiman, forest ecologist, Forestry Sciences Laboratory, Moscow, ID; David M. Ondov, forester, now located on the Flathead National Forest, Bigfork, MT; Hans Zuuring, University of Montana, School of Forestry, who served as Robert Keane's faculty advisor; and Norman L. Christensen, associate professor of botany and forest ecology at Duke University. We also received encouragement and help from numerous people on the National Forests in the Northern Region and from Robert Naumann and Wendel Hann at the Regional Office.

RESEARCH SUMMARY

This paper presents classifications of successional community types arising after clearcutting and fire treatments on four major forest habitat types in western Montana. A total of seven classifications were developed based upon data from 770 sample stands. Each classification represents sequences of seral community types found on sites capable of supporting a "potential vegetation type," similar to a habitat type phase. The classifications were based on analysis of data from treated (ages 4 to 80 years) and untreated stands on the four habitat types. Treated communities arose after stand-replacing wildfire and after clearcutting with broadcast burning, mechanical scarification, or no followup site or slash treatment. Paired treated and untreated stands located immediately adjacent to each other on the same site were chosen as the basis for the initial classification, which was later field tested and refined based on new data from a wide range of seral communities.

Within a given potential vegetation type, the highest level in the successional classification hierarchy is the structural stage. There are five stages: shrub-herb, sapling, pole, mature seral forest, and old-growth forest. The structural stage is determined using values of the following stand characteristics: tree canopy coverage (percent), diameter (d.b.h.) of dominant trees, basal area of trees, and stand age. Community types are then designated based upon the composition of undergrowth and overstory species. Probable pathways of succession or stand development are shown as arrows linking community types in the classification diagrams. In order to provide insight for vegetation management, the classifications also list the treatments and site or stand conditions associated with each posttreatment community type.

Simple diagnostic keys are provided for determining which of the seven successional classification diagrams is appropriate for use on a given stand and for identifying the successional community type. A brief description accompanies each classification and gives a synopsis of the successional patterns identified in the undergrowth and tree layers in relation to kind and intensity of treatment. This includes interpretations of natural and planted tree regeneration. Response of each major undergrowth species to various treatments across a range of habitat types is also summarized.

CONTENTS

FIGURES

TABLES

Forest Succession on Four Habitat Types in Western Montana

Stephen F. Arno
Dennis G. Simmerman
Robert E. Keane

INTRODUCTION

Reasons for Study

The publication "Forest Habitat Types of Montana" Pfister and others 1977) describes a system for classify-ng forest lands into "habitat types" based upon poten-ial or "projected" climax vegetation. Because the sys-em is based on the mature forest vegetation associated vith a habitat type, the publication offers only occa-ional inferences as to the development of seral commu-ities within habitat types. Nevertheless, the habitat ype classification has stimulated an interest in succes-ional patterns within habitat types and has also rovided a logical framework for studying forest uccession.

The need for understanding succession within each abitat type is heightened by the fact that, because of ire and logging, early to mid-seral community types ave been and will continue to be a major component of he forest landscape. Moreover, different silvicultural ractices allow land managers to develop markedly lifferent successional communities on a given habitat ype or even on a single site. The differences in seral ommunities are of great importance for timber produc-ion, forest protection (from wildfire, insects, and patho-gens), wildlife, range, watershed, recreation, and for natural area values.

This study was initiated in 1977 in order to develop lassifications of seral communities on a few major habi-at types in western Montana. Field sampling was car-ied out during four summers (1977-80), and then a re-iew draft classification was made available in 1982 and ntensively tested in the field during 1983. New data and efinements resulting from the field test have been incor-orated here. These classifications and the accompany-ng information can be used by land managers and esearchers as an aid in predicting successional develop-nent of forest communities (and treatment response) in elation to various types of cutting and fire treatments.

A comparatively brief description of methods is given ere; however, a detailed treatment, including recom-nended procedures for developing similar classifications n other habitat types or regions, is being prepared by he same authors. (The proposed outlet is **Forest cience.**)

Objectives

The major objectives of this study were: (1) to develop a general-purpose classification of the seral community types on selected habitat types; (2) to outline or model the successional sequences of community types on each habitat type; and (3) to document changes in canopy coverage by species during each successional sequence.

Secondary objectives were to interpret establishment and early growth of tree regeneration and development of undergrowth in relation to treatment and site characteristics.

Scope

This study was initiated as an attempt to classify the successional pathways that result from stand-replacing wildfire and clearcutting within selected habitat types, based on field sampling. A rather limited geographic area was chosen for study in order to minimize variation caused by regional differences in vegetation. The investigation was focused on four major forest habitat types that often lie adjacent to each other on the mountainous landscape of west-central Montana (fig. 1). This allows for comparison of succession on a group of different but related environments. According to the Lolo National Forest's detailed habitat type map, about 55 percent of the forest is occupied by these four habitat types.

Successional data were compiled for common stand-removing treatments: stand-replacing wildfire (WF); clearcutting without site preparation or slash treatment (NP); clearcutting followed by broadcast burning (BB); and clearcutting with mechanical scarification, usually dozer piling and burning (MS).

STUDY AREA

The study was concentrated on the Lolo and Bitterroot National Forests, the southern portion of the Flathead National Forest, and the Flathead Indian Reservation. This area is composed of rugged, heavily forested mountains separated by a few large grassland/agricultural valleys. Elevations range from about 3,000 ft (915 m) in the major valleys to 7,000 ft (2 135 m) or higher on the mountain ridges. Most of the land above 7,000 ft is in the slow-growing "upper subalpine forest" described by Pfister and others (1977).

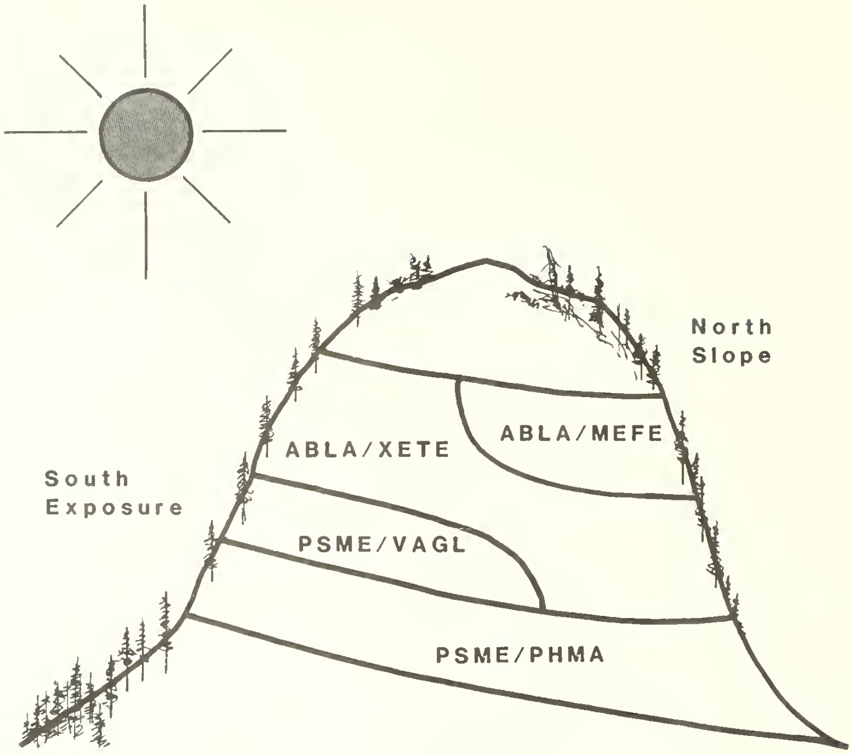


Figure 1.—Schematic distribution of some major forest habitat types in west-central Montana.

ABLA = Abies lasiocarpa
PSME = Pseudotsuga menziesii
MEFE = Menziesia ferruginea
PHMA = Physocarpus malvaceus
VAGL = Vaccinium globulare
XETE = Xerophyllum tenax

The surface geologic formation in the northern two-thirds of the study area is the Precambrian Belt Series, consisting primarily of quartzites and argillites. The southern third, largely in the Bitterroot National Forest, is mostly of granitic origin. In general, the forest soils are of medium to coarse texture and are shallow and rocky, reflecting the steep mountainous setting. Soil mantles on leeward slopes (generally facing north and east) are deeper than those on windward slopes, because of ancient wind-transported deposits of volcanic ash and loess.

Study sites apparently have three major subgroups of soils as described in the Soil Conservation Service (1975) classification: Cryoborolls on the warmest and driest sites; Cryandepts on sites having volcanic ash deposits; and Cryochrepts on most other sites. According to Nimlos (1963), most soils in these forests have a B_{ir} horizon 4 to 18 inches thick.

The climate of this portion of western Montana can be described as inland maritime. It is characterized by a cold, snowy winter; a cool, rainy spring; a short, warm-dry summer; and a cool-dry autumn. Mean annual precipitation ranges from about 15 inches (38 cm) in the drier *Pseudotsuga menziesii/Physocarpus malvaceus* (PSME/PHMA) sites to about 40 inches (102 cm) in the *Abies lasiocarpa/Menziesia ferruginea* (ABLA/MEFE) habitat type. Topography has a major influence on climate in this area. With increasing elevation, precipitation generally increases, while temperature decreases. North and east exposures are relatively cool and moist because of decreased insolation and better soil development and moisture retention. Conversely, steep south and west exposures tend to be warm and dry.

FIELD METHODS

Sampling Approach

In order to build a successional classification for a given habitat type, it was necessary to obtain data from stands representing different ages since treatment. It was judged unfeasible, however, to simply piece together a chronologic sequence of different stands arising after a given kind of treatment. Numerous attempts by others have shown that three major uncontrolled variables confound such an approach: (1) site variability within a habitat type; (2) geographic variations in vegetation; and (3) differences in stand history prior to treatment.

These sources of variation could be minimized by sampling an untreated or "control" stand immediately adjacent to each treated community (Zamora 1975). Field reconnaissance revealed that it was possible to locate one or more young communities (arising from fire or logging) as well as a remnant of the original stand, growing side by side on the same site with similar topography

and soils (fig. 2). Thus, the approach of sampling multiple stands on the same site was chosen as the basis for this study. It was possible to locate stands in each habitat type, ranging in age from 1 to 200 or more years since burning in a stand-replacing wildfire. Stands ranging up to about 30 years of age were available for the clearcutting treatments.

Long-term sampling of permanent plots on an annual basis would provide the most reliable data for constructing a classification of seral communities. For each habitat type and treatment, however, numerous plots would have to be established before treatment, and recorded for 100 years or more to cover only the early and middle stages of succession. Fortunately, Stickney (1980, in prep.) and Lyon and Stickney (1976) have begun this process and have provided detailed records of early successional changes after wildfires and broadcast burns on a few sites in the four habitat types. Because of the availability of these detailed early successional data—and to avoid the additional complexity of dealing with short-lived, early seral herbaceous plants that may initially become dominant—we concentrated sampling on communities 4 years or older since treatment.

Stand Selection

Using information from local foresters, we attempted to find stands representing a range of ages since treatment for each kind of treatment in each habitat type. We made reconnaissance trips to locate potential multiple sample stands (treated and untreated) on the same site. Potential sample stands were evaluated on apparent uniformity of treatment and adequate size for sampling. Multiple stands on what appeared to be the same site were then chosen for sampling based on reconnaissance evaluations. We attempted to obtain a good geographic dispersion of sample stands within the study area. Also, we sought to obtain a range of treatments and ages. Sites that had adjacent stands representing two or more treatments, and an untreated stand, were favored for sampling because of the extra information they would provide for comparisons.

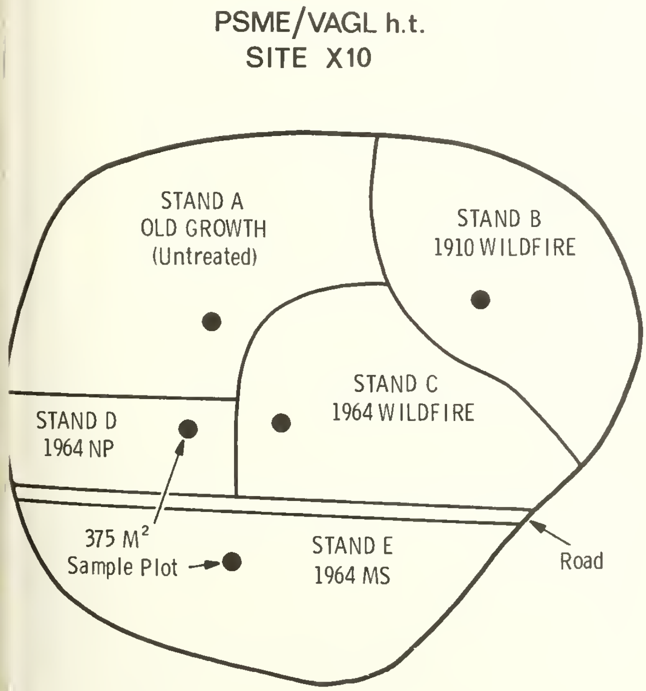


Figure 2.—Example of multiple stands having different treatments occurring on one site with similar soils and topography throughout. (NP = clearcut with no site or slash treatment; MS = clearcut and mechanically scarified.)

Sampling Procedures

Within all stands chosen for sampling, we assessed the variation in tree and undergrowth composition and in intensity of treatment. This assured that our nearly 1/10-acre (375-m^2) circular plot would be located in a representative area of the community. The plot size, location, and sampling procedures are similar to those employed in the Montana forest habitat type classification (Pfister and others 1977). Plot location procedure is described as "subjective without preconceived bias" by Mueller-Dombois and Ellenberg (1974), and is explained by Pfister and Arno (1980).

Scarified stands (dozer-pile and burn) are intricate mosaics of scraped areas, heavily burned areas, and areas that essentially escaped site treatment. On mechanically scarified stands, we set up a macroplot that included representative proportions of the treatment mosaic. It would have been informative to have sampled large numbers of small plots in each treated stand in order to document the microvariation; however, it would have necessitated a large effort to amass statistically based data of this sort. We chose to invest our limited resources on characterizing community types, rather than sampling mosaics within the communities.

Canopy-coverage data for all herbaceous and woody plants, including trees, were recorded as described by Pfister and Arno (1980), with each species' coverage being visually estimated within the entire macroplot. Coverage classes were recorded as follows: + = present in the stand, but not in the plot; T = less than 1 percent canopy coverage; 1 = 1-5 percent; 2 = 5-25 percent; 3 = 25-50 percent; 4 = 50-75 percent; 5 = 75-95 percent; 6 = 95-100 percent. Further, the numbered classes were split into a lower, middle, and upper range—for example, 2−, 2, and 2+—for additional refinement. (In retrospect, it would have been simpler to estimate coverages in 10 percent or 20 percent classes except for those under 5 percent.) To help enhance comparability of data, one investigator (Arno) was responsible for rating coverages of all species in all sample plots.

All trees were tallied by species and 2-inch diameter size classes. Stand history was determined through analysis of increment cores or cross-sections (taken near ground level) from trees regenerating after the disturbance and cross-sections from residual trees showing growth release or scars dating from disturbance (Arno and Sneck 1977). Records of site treatments were also obtained from district foresters.

Measurements of average depth of litter, fermentation, and humus layers on treated stands, in comparison to their untreated counterparts, indicated the relative intensity of treatment as did the percentage of exposed mineral soil. In clearcut broadcast-burned stands the completeness of combustion of various size classes of slash was observed. Texture of the mineral soil and the type of soil parent material were recorded in each stand.

Evidence of natural and planted tree regeneration was noted on treated sites and was also gleaned from management records. Stocking of established regeneration was estimated in three classes:

1. **Adequate** regeneration - more than 250 trees per acre and well distributed
2. **Inadequate** - between 100 and 250 per acre, or poorly distributed
3. **Nonstocked** - less than 100 per acre

Heights and total ages (from increment borings near ground level) were obtained for vigorous, free-growing, dominant trees of each species, as available. This information was used to calculate 50-year site indexes, as was done by Pfister and others (1977), and to represent timber productivity of young seral communities.

DEVELOPING THE CLASSIFICATION

Original Data Base

A total of 386 stands occupying 144 sites were sampled on the four habitat types; 242 stands had been treated, while the remaining 144 were untreated, mature stands including seven 100-year-old wildfire stands. The treated stands are divided as follows:

1. Stand-replacing wildfire, 79 stands (including the seven, 100-year-old stands also listed in the untreated category)
2. Clearcutting with broadcast burning, 46
3. Clearcutting with mechanical scarification, 68
4. Clearcutting with no site or slash preparation, 48
5. Other treatments (terracing), 8

Postclearcut sample stands generally ranged in age from 4 to 25 years in all habitat types; whereas post-wildfire stands were from 5 to 100 years old, with the majority over 50 years. Data from all sample stands were coded for computer-assisted analyses, which were carried out during each of the four winters on the newly compiled data and on the entire data set. Thus, the analyses (described later) were run repeatedly, with the help of different technicians, which allowed for repeated evaluations and refinements.

Verification and Refinement with Additional Data

A review draft of the classifications was distributed for field use by foresters and other land management specialists in May 1982. During the summer of 1983 the classifications were field tested as part of a cooperative study between the Intermountain Forest and Range Experiment Station and the University of Montana (Keane 1983). The classifications were applied in a total of 392 young seral communities located throughout the study area in four habitat types. These communities had resulted from wildfire and clearcutting with broadcast burning, mechanical scarification, and no site preparation. Unlike the original sampling, these stands were not required to be located adjacent to an untreated "control" stand. District foresters were also invited to independently apply the classifications to some of the same young communities. This resulted in a total of 73 seral stand evaluations made by 16 field personnel.

This evaluation (Keane 1983) showed that the classifications and keys fit well or satisfactorily in most sample stands, but pointed out numerous opportunities to refine the keys and presentation of the classifications. Keane (1983) also collected coverage class data for undergrowth and tree species at each test stand, and these data were pooled with those from the original study stands, greatly expanding the data base for classifications. Synthesis tables displaying data from all stands (770 in total, since eight from the Idaho side of the Bitterroot Range divide were not used in the final classification) were jointly interpreted by the three authors as the basis for refinements made since the 1982 review draft.

Defining Potential Vegetation Categories

The first step in constructing the classification was to evaluate the variation within each habitat type using data from all mature stands. The purpose of this was to judge whether the habitat types and phases of Pfister and others (1977) would provide a suitable environmental stratification for the successional classification. Three data banks were examined separately for major variations in potential vegetation within them (initial inspection revealed that potential vegetation differed greatly between these data banks):

1. PSME/PHMA h.t., 50 sites
2. PSME/VAGL and ABLA/XETE h.t.'s, 56 sites
3. ABLA/MEFE h.t., 38 sites

Index-of-similarity ordinations (Bray-Curtis polar ordinations as outlined in Pfister and Arno 1980) were constructed, based upon all the untreated stands in each data bank. This was done to detect differences in potential vegetation within a habitat type that may reflect substantial differences in sites. Synthesis or association tables were also used for a similar purpose (Mueller-Dombois and Ellenberg 1974; Pfister and Arno 1980). We looked for consistent differences, within each data bank, in the presence and canopy coverage of individual species and groups of species (herbs, shrubs, and trees). The goal was to evaluate differences in potential vegetation (the end point of succession) to be used as a basis for classification. In addition to examining untreated stands, we also inspected the data from younger communities to see if their vegetation seemed to reflect site-related differences.

The result of this investigation of potential vegetation categories is shown in figure 3, which compares the "potential vegetation types" used in this classification with Pfister and others' (1977) habitat types. Overall,

Warm and dry sites

Montana Forest Habitat Types (Pfister and others 1977)	"Potential Vegetation Types" for Successional Classification
PSME/PHMA h.t., CARU phase	PSME/PHMA, dry phase (LAOC poorly represented)
PSME/PHMA h.t., PHMA phase	PSME/PHMA, moist phase (LAOC well represented)
PSME/VAGL h.t., XETE phase	PSME/VAGL, XETE phase
ABLA/XETE h.t., VAGL phase	Sites with ABLA poorly represented
	ABLA/XETE, VAGL phase
ABLA/XETE h.t., VASC phase	ABLA/XETE, VASC phase
ABLA/MEFE h.t.	ABLA/MEFE, warm phase (PSME or LAOC common)
	ABLA/MEFE, cold phase (PSME and LAOC scarce)

Cold and moist sites

Figure 3.—Schematic representation of the relationship, along a gradient of environmental change, of our seven potential vegetation types to the habitat types of Pfister and others (1977).

the Pfister and others' habitat types seem quite suitable as a basis for our successional classifications, but we found it necessary to make some modifications, mostly at the phase level. These modifications are a result of a detailed inspection of a few habitat types in a limited area of Montana; thus, they may not be appropriate for application beyond this study.

Our seven potential vegetation types (fig. 3) can be described as follows: We have split the broad PSME/PHMA h.t. of western Montana into a dry and a moist phase, based upon the ability of these sites to support appreciable amounts ("well represented"—>5 percent canopy coverage) of western larch (*Larix occidentalis*). Several dry-site (for example, bunchgrass species) and moist-site plants (examples, *Linnaea borealis*, *Lonicera utahensis*, and *Pinus contorta*) also reflect the substantial variation in moisture across this habitat type. In our data, however, western larch was clearly the most ubiquitous indicator of relatively moist sites.

This phase split seems easier to apply than the one in Pfister and others (1977) and has direct application to succession, since western larch is a major overstory component only in the moist phase. Daubenmire (1973) made a similar environmental split, based upon western larch, within PSME/PHMA on the Priest River Experimental Forest in northern Idaho. We recognize the theoretical drawback of defining a phase on a successional tree species (western larch here, and larch and Douglas-fir, *Pseudotsuga menziesii*, in our ABLA/MEFE warm phase); however, these trees are very long-lived (>300 years) in most stands, and the frequency of disturbance has been sufficient to allow these species to perpetuate themselves in the vast majority of sites that seem climatically favorable for them. The dry phase of the PSME/PHMA seems to be more abundant in west-central Montana than the moist phase.

The southern portion of the Bitterroot National Forest lies beyond the geographic distribution of western larch, and thus has no PSME/PHMA moist phase as defined here. This southern portion is climatically drier than most of the study area and has less PSME/PHMA h.t. overall. It is possible that limited areas of PSME/PHMA moist phase conditions exist here, undetected in our sampling, and that they could be identified by the presence of *Linnaea borealis* or other moist-site species.

We have incorporated the warmest driest ABLA/XETE h.t. VAGL phase sites (Pfister and others 1977), along with the PSME/VAGL h.t., in our PSME/VAGL, XETE phase potential vegetation type. Stands on these sites (fig. 3) seem very similar successionally to other PSME/VAGL stands except for the addition of small amounts ("poorly represented"—<5 percent canopy coverage) of subalpine fir (*Abies lasiocarpa*), which does not become a major component even in old-growth stands.

Because of the above alteration, our ABLA/XETE, VAGL phase potential vegetation type includes slightly less environmental variation than the h.t. phase, while our PSME/VAGL, XETE phase potential vegetation type is broader than the h.t. phase itself. We have used Pfister and others' (1977) VASC phase without modification.

Pfister and others did not recognize phases within the ABLA/MEFE h.t.; however, we feel it necessary to define a warm and a cold phase. Douglas-fir or western larch are "common" (>1 percent canopy coverage) in the

warm phase and *Vaccinium scoparium* is "scarce" (<1 percent). The opposite is true of the cold phase, which is comparatively poor in overstory and undergrowth species. Much of our study area is at the geographic limits of the ABLA/CLUN h.t. on upland slopes, and it appears that our ABLA/MEFE warm phase is to some extent a geographical replacement for the ABLA/CLUN h.t., MEFE phase of northwestern Montana and northern Idaho.

After defining the seven potential vegetation types shown in figure 3, we set about constructing an individual successional classification for each one.

Classification Framework

STRUCTURAL STAGES

Upon inspection of successional patterns shown in the data for each of the seven potential vegetation types, it became apparent that the classification would have to deal with both changes in stand structure and species composition. The most promising approach for the highest level in the classification hierarchy seemed to be delineating simple structural or developmental stages, such as those used by Thomas (1979). Then, major differences in composition could be recognized within the appropriate structural stage.

In order to define a framework of structural stages, the following parameters from each sample stand were inspected for logical groupings: total percentage of canopy coverage by trees; d.b.h. of dominant trees; basal area per acre of tree stems; and years since treatment. This grouping process made it apparent that succession in each of the habitat type phases could be divided into five structural stages: (1) shrub-herb, (2) sapling, (3) pole, (4) mature seral forest, and (5) old-growth forest. The last stage includes both "near-climax" and "climax" forest conditions; the latter was seldom found in any of the four habitat types investigated in our study area. This structural stage classification is illustrated along the horizontal axis of figure 4. The lower part of figure 4 shows the range of values associated with each structural stage for tree canopy coverage and the other stand characteristics. The shrub-herb stage includes tree seedlings, but usually the young trees do not develop sufficient canopy coverage to warrant calling this a shrub-herb-seedling stage. Exceptions to this include the dense PICO seedling community types designated in the PSME/VAGL and ABLA/XETE potential vegetation types.

COMPOSITIONAL COMMUNITY TYPES

After segregating all stands associated with a potential vegetation type into the structural stages, the next step was to differentiate seral community types based upon characteristic tree and undergrowth species. Community types are listed vertically below the structural stages (fig. 4). The shade-tolerant undergrowth species (VAGL in fig. 4), are characteristic of pole stage and older communities. Under certain conditions, however, they are also major components of the younger stages. Other species, such as CARU and CEVE in figure 4, become the characteristic components only in younger communities.

We used synthesis tables, index-of-similarity ordinations, and cluster analyses (listed in order of decreasing usefulness) to aid in finding compositional groupings of stands in the shrub-herb and sapling stages. The approach was similar to that recommended by Pfister and Arno (1980). A certain amount of judgment based upon field sampling experience with these stands was also applied in the process of designating community types. Because of the limited number of sample stands in each stage, the rather small study area, and the lack of other classifications with which to compare, we have tended to recognize only the more obvious community types. Further sampling within our area, or expansion to other nearby areas, might well reveal community types that we have overlooked. We tended to designate community types based on major components of the undergrowth or the overstory. Also, we recognized either individual species or groups of ecologically similar species that showed rather consistent successional relationships. Finally, we developed simple stepwise keys for identifying community types within a potential vegetation type.

SUCCESSIONAL PATHWAYS

After the apparent community types had been differentiated, we attempted to define the usual pathways of succession or stand development. These successional pathways (shown as arrows on fig. 4) were discerned through analysis of data from sample stands of different ages on the same site. Also, trends in canopy coverage of successional species were identified and used as evidence for denoting pathways. For instance, coverages of fireweed (*Epilobium angustifolium*) and young conifers were inversely related. In contrast, huckleberry (*Vaccinium globulare*) tends to expand beneath the newly developing tree layer in a sapling stand. The process of identifying probable successional pathways based on stand data and knowledge of ecological relationships gave us insight for evaluating and refining some of our initial community type categories.

Interpreting Response to Treatment

RELATING TREATMENT TO COMMUNITY TYPE

After developing the successional classification associated with each potential vegetation type based on sample stand data, we attempted to link the kind and intensity of treatment to the initial (posttreatment) community type. Our information on treatment was based on field inspection and the available management records. Intensity of treatment could be rated in general, qualitative categories based upon the thickness of the surface organic layers, percentage of bare mineral soil exposed, and evidence of fine- or medium-sized woody fuels remaining after fire. Evaluations of treatment intensity had to be tempered by considering the amount of time and vegetal development since treatment.

We inspected the stand data to determine which kinds and intensities of treatment were associated with a given posttreatment community type (shrub-herb and sapling stages). Linkages to treatment were often unclear, but could be improved by also keeping track of the composition of untreated vegetation on the site and severeness

STRUCTURAL STAGES						
Community types	Row No.	SHRUB-HERB	SAPLING	POLE	MATURE SERAL FOREST	OLD GROWTH FOREST
	1	VAGL →	PSME / VAGL →	PSME / VAGL →	PSME / VAGL →	PSME / VAGL
	2	CARU →	PICO / CARU →	PICO-PSME / CARU		
	3	CEVE →	PICO / CEVE			

STAND CHARACTERISTICS					
Tree canopy cover (percent)	0-15	15-90	50-90	50-80	50-70
d.b.h. of dominant trees (inches)	0-1	2-5	6-10	11-15	16-25
Basal area (ft^2/acre)	0-1	2-100	100-250	100-250	150-250
Age (yr)	5-15	15-30	30-100	100-200	200-300

Figure 4.—Simplified classification for the purpose of illustration only.

of exposure and coarseness of soils. As a result of this data inspection, each successional classification has a box at the left showing treatments, pretreatment vegetation, or site conditions associated with early seral community types (example, fig. 5, page 11). These are general trends from our data.

SPECIES RESPONSE TO TREATMENT

In addition to providing a basis for classification of seral community types, the data from multiple stands on the same site allowed us to evaluate the response of each species to each kind of treatment within each potential vegetation type. In order to do this we set up tables that allowed for comparison of canopy coverages by species in paired (untreated vs. treated) stands. We used quantitative criteria (description on file at the Northern Forest Fire Laboratory, Missoula, MT), for rating the response of species to a given treatment. A brief interpretation of the response of each species is provided in the Species Response section of this report.

TREE REGENERATION RESPONSE

Tree regeneration data were taken as a small, auxiliary part of the study. The reconnaissance basis (rather than a statistical basis) of our field sampling and the emphasis on representing the entire plant community limited our ability to provide a detailed analysis of tree regeneration in relation to the successional classification. Nevertheless, some of the relationships of natural and planted regeneration to treatment by habitat type phases seem dramatic and can be interpreted at a low level of resolution from our data. Interpretations of tree regeneration are given in the narrative description of succession associated with each potential vegetation type. Fiedler (1982) also analyzed the regeneration data from our sample stands and drew conclusions on the relationship of regeneration success to habitat type, slope steepness and aspect, and treatment.

Keep in mind that our interpretations of planting success are based on results of widespread plantings done between the early 1960's and the mid-1970's. Artificial regeneration technology and field practices have improved substantially since then. Still, our observations indicate the relative ease or difficulty of obtaining artificial regeneration on the different phases and community types.

Identifying the Potential Vegetation Type of a Seral Stand

After major disturbances such as clearcutting or wildfire, it may be difficult to determine the appropriate habitat type on a site. The following guidelines are offered for such habitat type identification:

1. Apply the habitat type keys from Pfister and others (1977) to the least disturbed portions of the stand or to an adjacent stand on a similar topographic site that appears to represent a more mature stage on the same habitat type.
2. If the entire site is severely disturbed, perhaps a similar site with less disturbed vegetation can be found on the next ridge or valley.
3. Residual "islands" of pretreatment vegetation can often be found in logging units, and the prelogging or prefire tree community can usually be reconstructed by identifying the species and sizes of stumps (bark on old stumps is particularly helpful).
4. Habitat type maps are available for much of the national forest and Flathead Reservation lands; these can be used with caution for estimating habitat type when field evidence is poor.
5. If *Physocarpus malvaceus* is common and grand fir is not the indicated climax, the PSME/PHMA h.t. is likely. If *Menziesia ferruginea* is common (in the least disturbed areas) and *Clintonia uniflora* is scarce or absent, the ABLA/MEFE h.t. is likely.
6. Determine habitat type and phase using the Pfister and others keys and then use the key below to help identify the appropriate successional classification:

H.t. and phase (Pfister and others 1977)	Additional criteria	Potential vegetation type key (and page no.)
PSME/PHMA, CARU		PSME/PHMA, dry phase, p. 10
PSME/PHMA, PHMA	LAOC <5% canopy coverage (C.C.)	PSME/PHMA, dry phase, p. 10
	LAOC >5% C.C	PSME/PHMA, moist phase, p. 14
PSME/VAGL, XETE		PSME/VAGL, XETE, p. 18
ABLA/XETE, VAGL	ABLA <5%[1] C.C.	PSME/VAGL, XETE, p. 18
	ABLA >5% C.C.	ABLA/XETE, VAGL, p. 22
ABLA/XETE, VASC		ABLA/XETE, VASC, p. 26
ABLA/MEFE	PSME or LAOC >1% C.C.	ABLA/MEFE, warm phase, p. 30
	PSME and LAOC <1% C.C.	ABLA/MEFE, cold phase, p. 34

[1]This split may sometimes work better at the 25 percent level.

SUCCESSIONAL CLASSIFICATIONS BY POTENTIAL VEGETATION TYPE

1. Pseudotsuga menziesii/Physocarpus malvaceus (PSME/PHMA), Dry Phase

Site characteristics.—This phase is widespread and abundant in western Montana. It is usually associated with moderate to steep south- or west-facing slopes, but in relatively dry areas it occupies north or east aspects. Our sample stands were located between 3,200 and 5,800 ft (975 and 1 770 m) in elevation.

Mean site-index values for vigorous young dominant trees and mean maximum heights of old-growth trees on sample sites are shown in appendix C. These are compared with values derived by Pfister and others (1977) for the comparable habitat types in western Montana. Our field and office methods for determining site indexes are essentially the same as those of Pfister and others (see their p. 127-131). Our site-index and maximum-height values for the dry phase appear to be lower than those of Pfister and others for the habitat type as a whole.

Successional classification.—The following key to the successional classification for the PSME/PHMA dry phase (fig. 5) should be used to determine the appropriate community type for an unclassified stand.

KEY TO SUCCESSIONAL COMMUNITY TYPES WITHIN THE PSME/PHMA, DRY PHASE

Dry phase sites are those where western larch is "poorly represented" (<5 percent canopy coverage) in stands of all ages, as indicated on page 9.

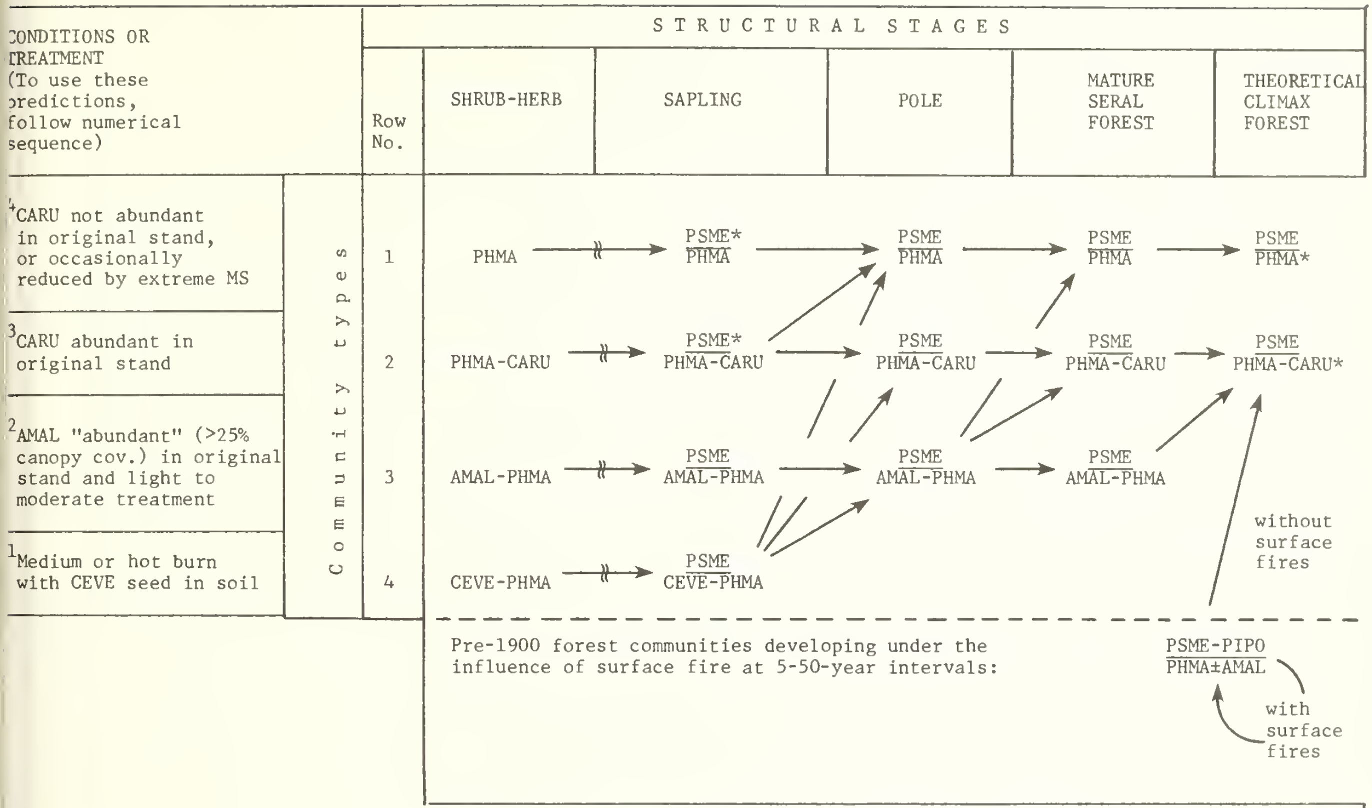
1. Select the most appropriate **community type row number** for the stand in question through use of the undergrowth key below (first priority). Then compare the tree species composition (second priority) with the community type names for that row in figure 5.

Stop at the first requirement that fits:[2]	COMMUNITY TYPE ROW NUMBER (in fig. 5)
a. *Ceanothus velutinus* >5% canopy coverage (C.C.)	4
b. *Amelanchier alnifolia* or *Acer glabrum* or *Salix scouleriana* or their combined coverages >15%	3
c. *Calamagrostis rubescens* or *Carex geyeri* or their combined coverages >25%	2
d. None of above; *Physocarpus malvaceus* >5% C.C.	1

2. Select the most appropriate **structural stage** for the stand by comparing it with the stand characteristic values listed in figure 5 for tree canopy coverage, average d.b.h. of dominant trees, stand basal area, and stand age.

3. Inspect appendix A-1, which shows constancy and average canopy coverages of different species in each community type. Is the stand in question compositionally similar to sample stands shown in the indicated community type? If so, it apparently "fits" that community type. If it is dissimilar in terms of major component species, compare it with the other community types listed. It may fit one of those types, or it may not fit this classification at all, which was true of two of the 148 stands (1.4 percent) we sampled.

[2] In stands where undergrowth is obviously depauperate (unusually sparse) because of dense shading or duff accumulations, coverage requirements for the climax species (in this case, community type rows 1 and 2) can be reduced.



		SHRUB-HERB	SAPLING	POLE	MATURE SERAL FOREST	THEORETICAL CLIMAX FOREST
Stand Characteristics by Structural Stage (Range represents about 90% of the data; extreme values are shown in parentheses)						
Range of values from sample stands	Tree canopy coverage percent	0 - 15	15 - 60(90)	45 - 85	(30)40 - 75	
	Average d.b.h. of dominant trees (inches)	0 - 2	2 - 6	6 - 14	12 - 24	
	Basal area (ft^2/acre)	0 - 6	5 - 60(133)	70 - 200	100 - 260	
	Stand age (yr)	3 - 30	13 - 50	50 - 85	100 - 300 +	
Number of sample stands		63	27	23	33	

TREATMENT CODES:
- BB = Clearcut with broadcast burn
- MS = Clearcut with mechanical scarification (dozerpile and burn)
- WF = Stand replacing wildfire
- ≀≀ = Establishment of natural tree regeneration delayed ≧ 20 years
- ± = with or without

TREES:
- PSME = Pseudotsuga menziesii
- PIPO = Pinus ponderosa

UNDERGROWTH:
- CEVE = Ceanothus velutinus
- PHMA = Physocarpus malvaceus
- AMAL = Amelanchier alnifolia (alternate indicators for AMAL are Acer glabrum and Salix scouleriana)
- CARU = Calamagrostis rubescens (alternate indicator for CARU is Carex geyeri)

Figure 5.—Successional community types (with natural tree regeneration) on the PSME/PHMA dry phase in western Montana. (Dry phase sites are defined as those where western larch is "poorly represented" in stands of all ages.) Constancy and coverage data for each community type are shown in appendix A-1. An asterisk indicates hypothesized community types without data. The box at left shows relationship of conditions and treatment to posttreatment community type, based on our data.

INTERPRETATIONS OF SUCCESSION

Undergrowth.—As figure 5 shows, we found that PHMA is essentially a permanent member of all successional sequences. Considering the principal codominant vegetation, however, we have identified three kinds of undergrowth ("unions") that persist in mature stands (fig. 5, rows 1-3). As indicated in the "condition or treatment" box in figure 5, the composition of pretreatment undergrowth largely masks the effects of treatment. The notable exception to this trend is the emergence of an early seral CEVE-PHMA community (row 4) after relatively hot fire treatments where CEVE seed persists in the soil. Unfortunately, it is a very laborious process to discover whether or not CEVE seed is present in the surface soil. A possible alternative would be to investigate the surrounding area thoroughly to see if CEVE plants are found in openings or disturbed sites (such as south-facing road cuts). If CEVE is present in the immediate vicinity on similar sites, it could be assumed that CEVE seeds occur in the soil. CEVE is highly intolerant of shade and dies out rapidly when young conifers begin to form a moderately dense canopy.

AMAL, ACGL, and SASC (fig. 5, row 3) are long-lived seral species in the dry phase that regenerate principally from root crown resprouting. Their coverage tends to increase in response to a BB or WF treatment and decrease in maturing stands, but often these tall shrubs have remained as a major component of the undergrowth even in mature stands. In mature stands, vigor and twig production has no doubt declined compared with early seral conditions.

PHMA-CARU (row 2) is the most prevalent undergrowth in mature stands, and, in the absence of CEVE seeds, the CARU or CAGE component is usually able to maintain or quickly regain dominance after burning or scarification treatments. The PHMA community type (row 1) was sampled in only two mature stands in Montana, while all four of the Salmon National Forest stands fit here. Responses of individual species by treatment type are discussed under Species Response.

Table 1 illustrates by specific examples that frequency of treatments and the pretreatment vegetation (Lyon and Stickney 1976) are important factors influencing the resulting vegetation. This table summarizes the treatment history and dominant vegetation on two PSME/PHMA dry phase sites where several different stands occur adjacent to each other. Stands 11D (that is "site 11, stand D") and 42C were burned more frequently than their neighbors, and as a result, seral shrub species like CEVE, SASC, and AMAL became dominant components. Conversely, stands 11B and 42D had gone so long without burning that recent wildfires did not result in an abundance of seral shrubs. In 42D, however, enough CEVE appeared to classify it CEVE-PHMA community type.

Cholewa and Johnson (1983) recently described succession in 27 communities in the *Pseudotsuga/Physocarpus* h.t. in northern Idaho; they represent succession as a continuum and do not offer a classification as such. Robert Steele (Intermountain Forest and Range Experiment Station, Boise, ID) has produced an unpublished classification of this habitat type in central Idaho using cone-shaped models for differentiating various tree, shrub, and herbaceous layer types; the approach is described in Steele (1984). Hann (1982) used a similar cone-model approach to classify seral community types on the *Pseudotsuga menziesii/ Linnaea borealis* h.t. in western Montana.

Trees.—Tree regeneration is difficult to obtain in the PSME/PHMA dry phase. Natural regeneration often required more than 20 years to become established. Planting (1960's to mid-1970's practices) was successful about half the time, and then mostly on terraced or scarified microsites. Natural regeneration that did occur was quite delayed and is predominantly Douglas-fir. In contrast, mature, untreated stands are composed of Douglas-fir and ponderosa pine, and about 80 percent of the >100-year-old stands show evidence of a history of underburning prior to about 1920. Occasional underburns evidently maintained mixed stands on most of these sites, as illustrated in figure 5, lower right. Our data for the PSME/PHMA and PSME/PHMA-CARU community types in the Mature Seral Forest stage (in appendix 5) represent vestiges of these conditions where PIPO has not yet passed out of the picture successionally although AMAL (and ACGL and SASC) may have been reduced in coverage as a result of >60 years of fire suppression. Although the pine is well adapted to most dry phase sites, it seldom regenerates adequately without planting after clearcutting or stand-replacing wildfire. Relatively frequent underburning generally favored dominance by ponderosa pine, while less frequent burning (with occasional severe fires) favored Douglas-fir. Hypothesized tree succession scenarios under different disturbance regimes are shown in appendix D-1.

Table 1.—*Examples of different vegetative communities arising in response to past treatments at two sites in the PSME/PHMA, dry phase*

Site No.	Stand letter	Treatment and year 1840	1910	1972	Dominant vegetation (overstory / undergrowth)	Seral community type	Structural stage (age)
P 11	A[1]	WF	—	—	PSME / PHMA	PSME/PHMA – CARU	Mature seral forest (137)
Sampled	B	WF	—	WF	none / PHMA, SPBE	/PHMA	Shrub – herb (5)
in 1977	C	WF	WF	—	PSME / PHMA, ACGL, AMAL	PSME/AMAL – PHMA	Pole (67)
	D	WF	WF	WF	none / CEVE, ACGL, AMAL, PHMA	/CEVE – PHMA	Shrub – herb (5)
		1865 & 1872	1900	1964			
P 42	A[2]	understory fires	—	—	PSME / PHMA, SPBE	PSME/PHMA	Mature seral forest (250) (near climax)
Sampled	B	"	WF	—	PSME / PHMA	PSME/PHMA	Pole (79)
in 1979	D	"	—	WF	none / PHMA, SPBE, CEVE	/CEVE – PHMA	Shrub – herb (15)
	C	"	WF	WF	none / CEVE, SASC, PHMA	/CEVE – PHMA	Shrub – herb (15)
	E	"	—	BB	none / SPBE, CEVE, PHMA	/CEVE – PHMA	Shrub – herb (15)

Species abbreviations:
- ACGL = *Acer glabrum*
- AMAL = *Amelanchier alnifolia*
- CEVE = *Ceanothus velutinus*
- CARU = *Calamagrostis rubescens*
- PHMA = *Physocarpus malvaceus*
- SASC = *Salix scouleriana*
- SPBE = *Spiraea betulifolia*
- PSME = *Pseudotsuga menziesii*

Treatment abbreviations:
- BB = clearcut and broadcast burned
- WF = stand – replacing wildfire

[1]Plant Creek site: 5,500 ft (1 680 m) elev., SE. aspect, 11 mi (18 km) SE. of Missoula, MT.
[2]Second Creek site: 5,300 ft (1 620 m) elev., SW. aspect, 10 mi (16 km) ESE. of Superior, MT.

2. *Pseudotsuga menziesii/Physocarpus malvaceus* (PSME/PHMA), Moist Phase

Site characteristics.—This phase is not as widespread in western Montana as the dry phase. It is essentially absent in the Bitterroot River drainage south of Stevensville and in the Clark Fork drainage east of Rock Creek. The moist phase occurs primarily on moderate to steep, north- and east-facing slopes and was sampled between 3,400 and 5,300 ft (1 040 and 1 620 m) in elevation. It often occurs on south-facing slopes in the moist areas of northwestern Montana. It usually does not extend as high as the dry phase, but instead, is replaced by cooler habitat types near the 5,000-ft (1 525-m) level. Our site-index data for the moist phase are similar to those of Pfister and others (1977) for the entire habitat type (appendix C).

Successional classification.—The following key to the successional classification for the PSME/PHMA moist phase (fig. 6), should be used to determine the appropriate community type for an unclassified stand.

KEY TO SUCCESSIONAL COMMUNITY TYPES WITHIN THE PSME/PHMA, MOIST PHASE

Moist phase sites are those that can support appreciable amounts (>5 percent canopy coverage) of western larch, as indicated on page 9.

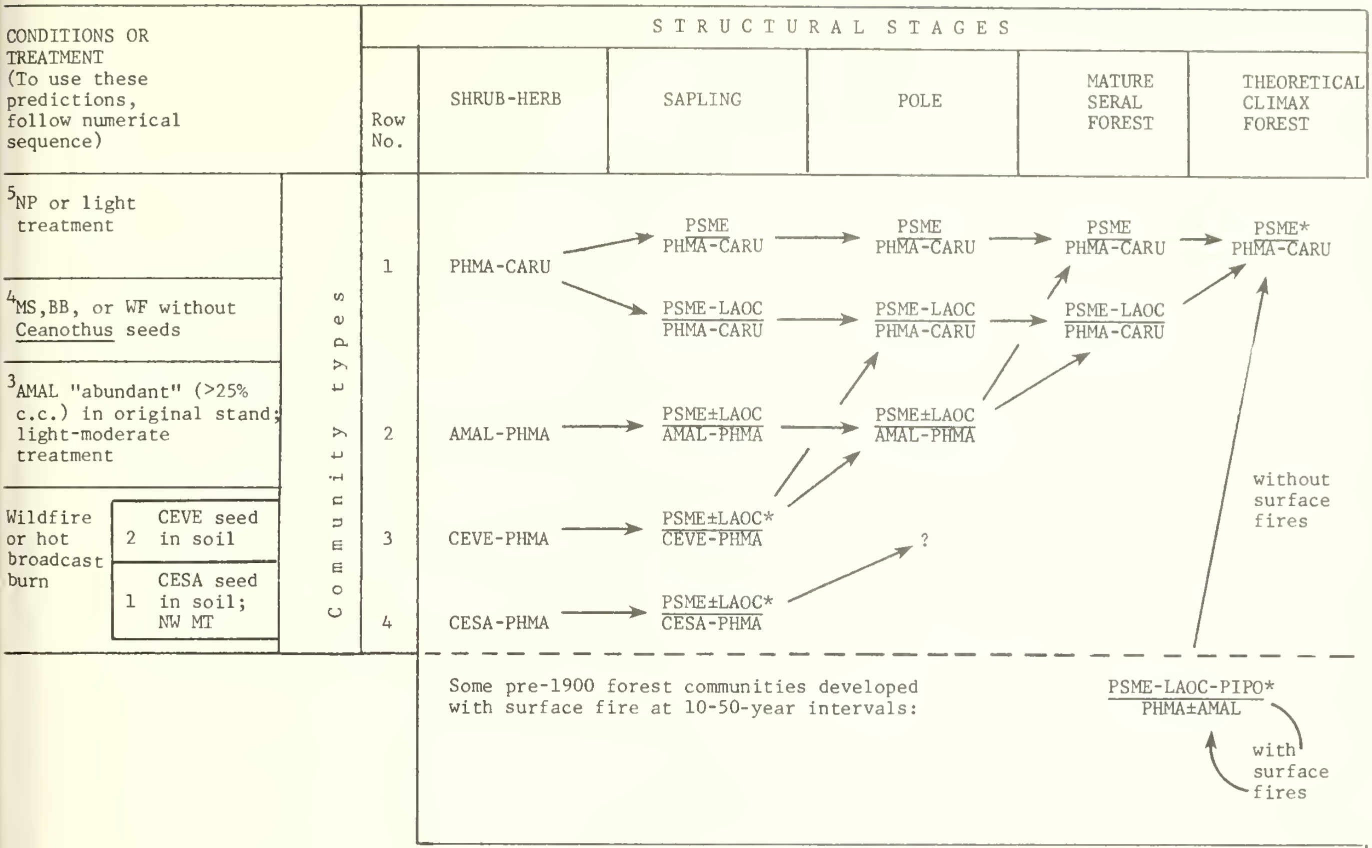
1. Select the most appropriate **community type row number** for the stand in question through use of the undergrowth key below (first priority). Then compare the tree species composition (second priority) with the community type names for that row in figure 6.

Stop at the first requirement that fits:[3]	COMMUNITY TYPE ROW NUMBER (in fig. 6)
a. *Ceanothus sanguineus* >5% canopy coverage (C.C.)	4
b. *Ceanothus velutinus*>5% C.C.	3
c. *Amelanchier alnifolia* or *Acer glabrum* or *Salix scouleriana* or their combined coverages >15%	2
d. *Calamagrostis rubescens* or *Carex geyeri* or their combined coverages>25%	1
(If *Larix occidentalis* is well represented among trees or regeneration, choose the PSME-LAOC overstory pathway.)	

2. Select the most appropriate **structural stage** for the stand by comparing it with the stand characteristic values listed in figure 6 for tree canopy coverage, average d.b.h. of dominant trees, stand basal area, and stand age.

3. Inspect appendix A-2, which shows constancy and average canopy coverages of different species in each community type. Is the stand in question compositionally similar to sample stands shown in the indicated community type? If so, it apparently "fits" that community type. If it is dissimilar in terms of major component species, compare it with the other community types listed. It may fit one of those types, or it may not fit this classification at all, which was true of one of the 80 stands (1.3 percent) we sampled.

[3]In stands where undergrowth is obviously depauperate (unusually sparse) because of dense shading or duff accumulations, coverage requirements for the climax species (in this case, community type row 1) can be reduced.



Stand Characteristics by Structural Stage
(Range represents about 90% of the data; extreme values are shown in parentheses)

		Shrub-herb	Sapling	Pole	Mature seral forest	Theoretical climax forest
Range of values from sample stands	Tree canopy coverage percent	0 - 15(30)	20 - 75	65 - 90	40 - 70	
	Average d.b.h. of dominant trees (inches)	0 - 2	2 - 5	6 - 12	11 - 18	
	Basal area (ft^2/acre)	0 - 3	8 - 55(180)	(47)70 - 210	140 - 210+	
	Stand age (yr)	3 - 20	13 - 45(58)	55 - 90	90 - 250	
Number of sample stands		39	18	11	11	

REATMENT CODES:
BB = Clearcut with broadcast burn
MS = Clearcut with mechanical scarification (dozerpile and burn)
NP = Clearcut with no site or slash treatment
WF = Stand replacing wildfire
± = with or without

TREES:
PSME = _Pseudotsuga menziesii_
LAOC = _Larix occidentalis_
PIPO = _Pinus ponderosa_

UNDERGROWTH:
CESA = _Ceanothus sanguineus_
CEVE = _Ceanothus velutinus_
PHMA = _Physocarpus malvaceus_
AMAL = _Amelanchier alnifolia_ (alternate indicators for AMAL are _Acer glabrum_ and _Salix scouleriana_)
CARU = _Calamagrostis rubescens_ (alternate indicator for CARU is _Carex geyeri_)

Figure 6.—Successional community types (with natural tree regeneration) on the PSME/PHMA moist phase in western Montana. (Moist phase sites are those that can support appreciable amounts [>5 percent canopy coverage] of western larch.) Constancy and coverage data for each community type are shown in appendix A-2. An asterisk indicates hypothesized community types without data. The box at left shows the relationship of conditions and treatment to posttreatment community type, based on our data.

INTERPRETATIONS OF SUCCESSION

Undergrowth.—It appears that only the PHMA-CARU undergrowth community persists beneath mature stands (fig. 6). The CARU and CAGE component of this community maintained or quickly reestablished itself regardless of site preparation. Undergrowth succession parallels that found on the dry phase except for the addition of a CESA-PHMA community type (in the western part of northwestern Montana) and that AMAL, ACGL, and SASC do not remain as a major component in mature stands. Responses of undergrowth species by treatment are discussed in the Species Response section.

Trees.—Tree regeneration was not as delayed as in the dry phase. Fully stocked natural regeneration was established within 10 years in about half the stands. The delayed natural regeneration that occurred in other stands was nearly all Douglas-fir. After the fire or scarification treatments, Douglas-fir and western larch usually regenerated, eventually developing into mixed, mature seral forests. Half of the untreated mature stands sampled had been underburned by wildfires prior to 1920. In these stands light to moderate surface fires generally at 10- to 50-year intervals maintained open, mature forests of Douglas-fir, larch, and ponderosa pine as illustrated in figure 6, lower right. Hypothesized tree succession scenarios under different disturbance regimes are shown in appendix D-2.

3. *Pseudotsuga menziesii/Vaccinium globulare, Xerophyllum tenax* Phase (PSME/VAGL,XETE)

Site characteristics.—This phase is widespread throughout the study area on moderate to steep slopes (on all aspects, but least commonly northern aspects). Our sample stands were located between 4,800 and 6,800 ft (1 460 and 2 070 m) in elevation. Our site-index and maximum-height data (appendix C) substantially agree with those of Pfister and others (1977) for their PSME/VAGL h.t. as a whole. Our Douglas-fir site indexes appear to be higher; however, we sampled more young vigorous stands than did Pfister and others.

Successional classification.—The following key to the successional classification for PSME/VAGL, XETE phase (fig. 7), should be used to determine the appropriate community type for an unclassified stand.

KEY TO SUCCESSIONAL COMMUNITY TYPES WITHIN THE PSME/VAGL, XETE PHASE

ABLA/XETE h.t., VAGL phase sites (Pfister and others 1977) where ABLA is poorly represented in mature stands are included here, as indicated on page 9.

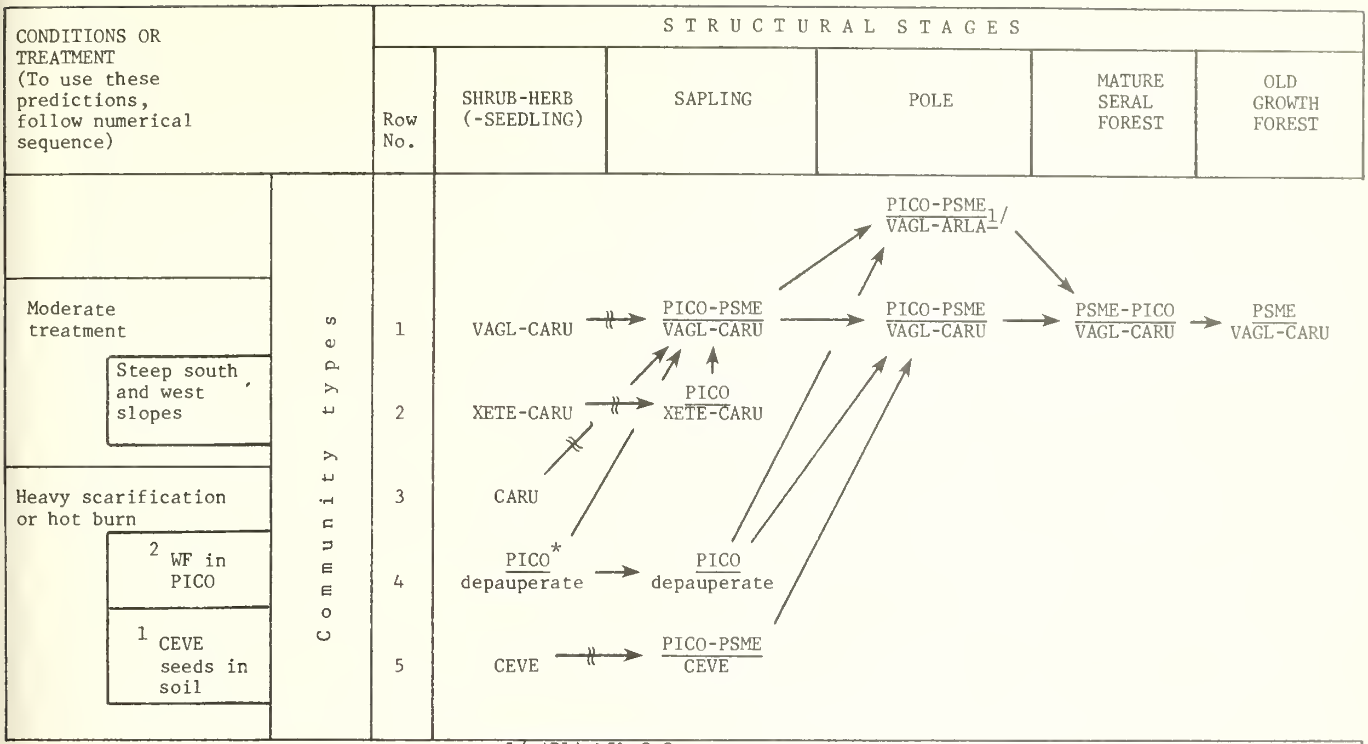
1. Select the most appropriate **community type row number** for the stand in question through use of the undergrowth key below (first priority). Then compare the tree species composition (second priority) with the community type names for that row in figure 7.

Stop at the first requirement that fits:[4]	COMMUNITY TYPE ROW NUMBER (in fig. 7)
a. *Ceanothus velutinus* >5% canopy coverage (C.C.)	5
b. *Vaccinium globulare* >5% C.C.	1
c. *Xerophyllum tenax* >5% C.C.	2
d. *Calamagrostis rubescens* or *Carex geyeri* or their combined coverages >25%	3
e. Dense *Pinus contorta* seedling or saplings	4

2. Select the most appropriate **structural stage** for the stand by comparing it with the stand characteristic values listed in figure 7 for tree canopy coverage, average d.b.h. of dominant trees, stand basal area, and stand age.

3. Inspect appendix A-3, which shows constancy and average canopy coverages of different species in each community type. Is the stand in question compositionally similar to sample stands shown in the indicated community type? If so, it apparently "fits" that community type. If it is dissimilar in terms of major component species, compare it with the other community types listed. It may fit one of those types, or it may not fit this classification at all, which was true of three of the 124 stands (2.4 percent) we sampled.

[4]In stands where undergrowth is obviously depauperate (unusually sparse) because of dense shading or duff accumulations, coverage requirements for the climax species (in this case, community type row 1) can be reduced.



1/ ARLA >5% C.C.

Stand Characteristics by Structural Stage
(Range represents about 90% of the data; extreme values are shown in parentheses)

		SHRUB-HERB (-SEEDLING)	SAPLING	POLE	MATURE SERAL FOREST	OLD GROWTH FOREST
Range of values from sample stands	Tree canopy coverage percent	0 - 15(30)	15 - 90	60 - 90	55[2/] - 72	45 - 70
	Average d.b.h. of dominant trees (inches)	0 - 2	2 - 5	6 - 10	11 - 16	14 - 24
	Basal area (ft^2/acre)	0 - 9	3 - 90(143)	45 - 130(321)	120 - 240	140 - 330
	Stand age (yr)	4 - 23	12 - 32(54)	(25)39 - 90	100 - 230	190 - 300+
Number of sample stands		51	33	13	9	15

TREES:
PICO = Pinus contorta
PSME = Pseudotsuga menziesii
≀≀ = Establishment of tree regeneration delayed ≥ 20 years

UNDERGROWTH:
CEVE = Ceanothus velutinus
CARU = Calamagrostis rubescens
VAGL = Vaccinium globulare
XETE = Xerophyllum tenax
ARLA = Arnica latifolia

2/ In two stands one-half or less of the coverage was from overstory trees.

Figure 7.—Successional community types (with natural tree regeneration) on the PSME/VAGL, XETE phase in western Montana (including ABLA/XETE h.t., VAGL phase sites where ABLA is poorly represented in mature stands). Constancy and coverage data for each community type are shown in appendix A-3. An asterisk indicates hypothesized community types without data. The box at left shows the relationship of conditions and treatment to posttreatment community type, based on our data.

INTERPRETATIONS OF SUCCESSION

Undergrowth.—The VAGL-CARU undergrowth (fig. 7, row 1), which includes XETE, is persistent in old stands and remains dominant after light to moderate intensity clearcut and burn treatments on "moderate" topographic sites—namely, **not** on steep south-to-west aspects or on sites with very coarse surface soils. In contrast, on severely wind- or sun-exposed sites, VAGL decreases drastically in coverage even after a clearcut with no site or slash treatment or a light broadcast burn. This results in a XETE-CARU community type (row 2). Our observations suggest that the stems of VAGL are killed back by subzero (degrees Fahrenheit) temperatures when there is little snowpack on these exposed sites.

If there is CEVE seed in the soil, a hot burn will result in the CEVE community type (row 5). Otherwise, a hot burn, heavy scarification, or a moderate treatment on a severely exposed site kills most XETE plants, as well as VAGL, and generally yields a CARU and CAGE dominated community (row 3). After a hot wildfire in a lodgepole pine stand (example, the Sleeping Child Burn), the tendency was to regenerate a dense (doghair) community of lodgepole pine seedlings with depauperate undergrowth (row 4).

All seral undergrowth communities evidently develop into VAGL-CARU beneath the dense overstory of a pole stage. Sometimes the CARU and CAGE element apparently was largely shaded out by this dense overstory and ARLA replaced the grasses. As the stand matured and became less shady, however, the CARU and CAGE again became abundant (>25 percent canopy coverage).

Table 2 gives an example of how different treatments sometimes produce diverse responses on a single site on this habitat type. Figure 2 (p. 3) is a map of these stands. VAGL was severely reduced in stand 10D by simply removing the forest cover (NP treatment) and exposing the undergrowth to sun, wind, and frost or winter desiccation damage on this dry, south slope. A similar result occurred after wildfire (stand 10C) except that mineral soil was exposed, allowing lodgepole pine to regenerate. The scraping and hot burning of dozer piles in 10E killed XETE as well as VAGL and allowed a denser stand of lodgepole pine and seral shrubs to develop.

Trees.—Full stocking of natural regeneration usually required 20 years or more for establishment, except after wildfire and sometimes after scarification treatments. Lodgepole pine regenerated more successfully than other species in most stands. Planting (1960's to mid-1970's practices) was usually judged unsuccessful in our sample stands. Lodgepole pine dominated the early stages of tree succession after wildfire, and often after clearcutting with site or slash treatments. Douglas-fir increases in the understory and assumes dominance in the mature seral forest stage. Larch is often a minor component of seral stands. More than 60 percent of the mature stands sampled had experienced one or more understory wildfires prior to 1920.

Table 2.—*Examples of different vegetative communities arising in response to past treatments at one site in the PSME/VAGL, XETE potential vegetation type*

Site No.	Stand letter	Treatment and year 1910	1964	Dominant vegetation Overstory / Undergrowth	Seral community type	Structural stage (age in years)
X-10	A[1]	—	—	PSME – ABLA / XETE, VAGL	PSME/VAGL – CARU	Old growth forest (250)
Sampled	B	WF	—	PICO – PSME / VAGL, XETE	PICO – PSME/VAGL – ARLA	Pole (68)
in 1978	D	—	NP	none / XETE, CARU	XETE – CARU	Shrub – herb (14)
	C	—	WF	PICO / XETE, CARU	PICO/XETE – CARU	Sapling (14)
	E	—	MS	PICO / CEVE, SASC	PICO – PSME/CEVE	Sapling (14)

Species abbreviations:
- CEVE = *Ceanothus velutinus*
- CARU = *Calamagrostis rubescens*
- SASC = *Salix scouleriana*
- VAGL = *Vaccinium globulare*
- XETE = *Xerophyllum tenax*
- ABLA = *Abies lasiocarpa*
- PICO = *Pinus contorta*
- PSME = *Pseudotsuga menziesii*

Treatment abbreviations:
- MS = clearcut and mechanically scarified
- NP = clearcut with no site preparation
- WF = stand-replacing wildfire

[1]Saint Mary Peak site: 6,600 ft (2 010 m) elevation, south aspect, 5 miles west of Stevensville, MT.

4. *Abies lasiocarpa/Xerophyllum tenax, Vaccinium globulare* Phase (ABLA/XETE, VAGL)

Site characteristics.—This phase is abundant in the study area and was found primarily at elevations of 5,000 to 7,200 ft (1 520 to 2 200 m) usually on moderate to steep slopes, often directly upslope from the PSME/VAGL, XETE phase. It was found on all aspects but was less common on north and east aspects. Our site-index and maximum-height data (appendix B) are similar to those of Pfister and others (1977) for the entire ABLA/XETE habitat type.

Successional classification.—The following key to the successional classification for the ABLA/XETE, VAGL phase (fig. 8), should be used to determine the appropriate community type for an unclassified stand.

KEY TO SUCCESSIONAL COMMUNITY TYPES WITHIN THE ABLA/XETE, VAGL PHASE

Sites where ABLA is poorly represented in mature stands are included in our PSME/VAGL h.t. classification, as indicated on page 9.

1. Select the most appropriate **community type row number** for the stand in question through use of the undergrowth key below (first priority). Then compare the tree species composition (second priority) with the community type names for that row in figure 8.

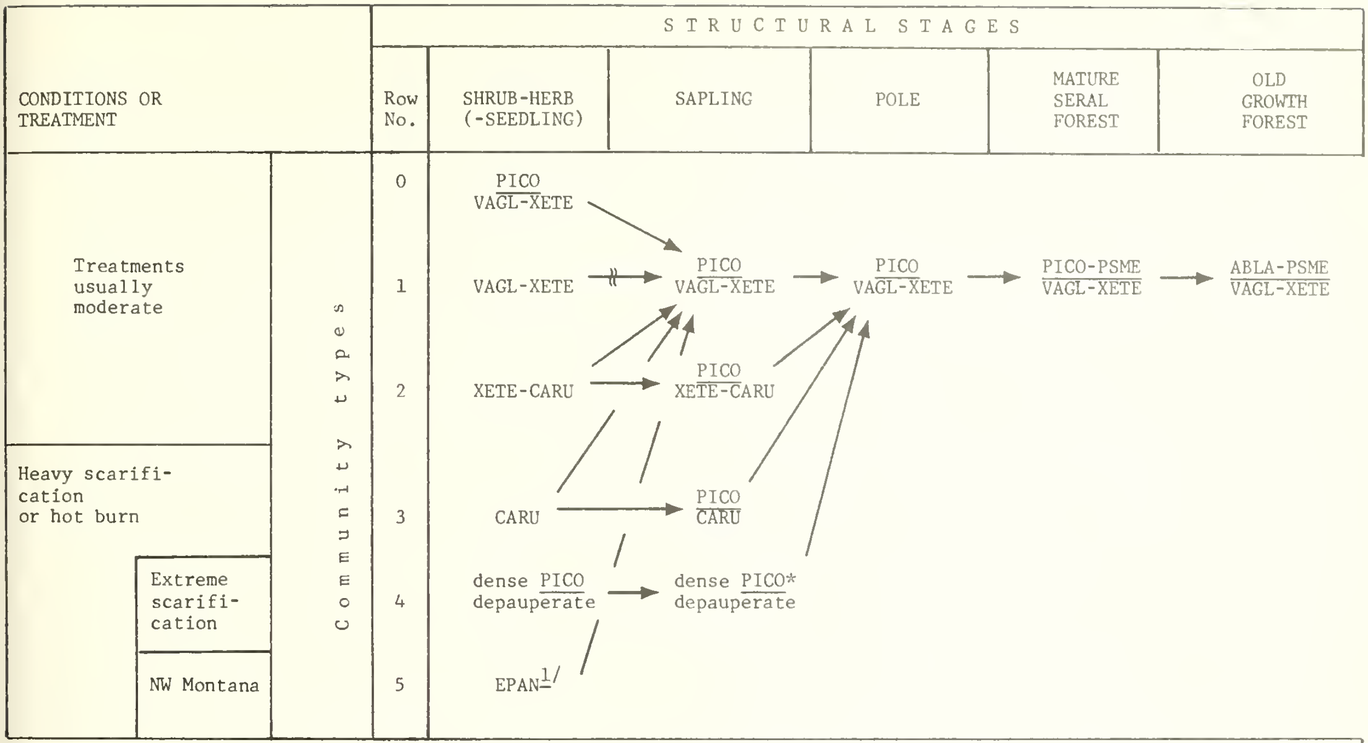
Stop at the first requirement that fits:[5]	COMMUNITY TYPE ROW NUMBER (in fig. 8)
a. *Epilobium angustifolium* or *Anaphalis margaritacea* or their combined coverages >25%	5
b. *Vaccinium globulare* >5% canopy coverage (C.C.) and *Pinus contorta* or *Larix* or *Pseudotsuga* seedlings or their combined coverages >15%	0
c. *Vaccinium globulare* >5% C.C.	1
d. *Xerophyllum tenax* >5% C.C.	2
e. *Calamagrostis rubescens* or *Carex geyeri* or their combined coverages >25%	3
f. Not as above; dense *Pinus contorta* seedlings or saplings	4

2. Select the most appropriate **structural stage** for the stand by comparing it with the stand characteristic values listed in figure 8 for tree canopy coverage, average d.b.h. of dominant trees, stand basal area, and stand age.

3. Inspect appendix A-4, which shows constancy and average canopy coverages of different species in each community type. Is the stand in question compositionally similar to sample stands shown in the indicated community type? If so, it apparently "fits" that community type. If it is dissimilar in terms of major component species, compare it with the other community types listed. It may fit one of those types, or it may not fit this classification at all, which was true of two of the 127 stands (1.6 percent) we sampled.

---

[5] In stands where undergrowth is obviously depauperate (unusually sparse) because of dense shading or duff accumulations, coverage requirements for the climax species (in this case, community type row 1) can be reduced.



Stand Characteristics by Structural Stage
(Range represents about 90% of the data; extreme values are shown in parentheses)

		SHRUB-HERB (-SEEDLING)	SAPLING	POLE	MATURE SERAL FOREST	OLD GROWTH FOREST
Range of values from sample stands	Tree canopy coverage percent	0 - 15(70)	15 - 60(90)	55 - 90	30 - 70	40 - 90
	Average d.b.h. of dominant trees (inches)	0 - 2	2 - 5	5 - 11	10 - 15(19)	12 - 22
	Basal area (ft^2/acre)	0 - 6	3 - 60	60 - 200(393)	70 - 300	(68)120 - 330
	Stand age (yr)	4 - 22	(12)15 - 41(80)	41 - 105	130 - 250	(150)220 - 300+
Number of sample stands		57	28	17	14	9

TREES:
- ABLA = _Abies lasiocarpa_
- PICO = _Pinus contorta_
- PSME = _Pseudotsuga menziesii_

UNDERGROWTH:
- CARU = _Calamagrostis rubescens_
- VAGL = _Vaccinium globulare_
- XETE = _Xerophyllum tenax_
- EPAN = _Epilobium angustifolium_

≀≀ = Establishment of tree regeneration delayed = 20 years.

1/ Occasionally _Ribes viscosissimum_ dominates in sites that are nearly ABLA/MEFE h.t.

Figure 8.—Successional community types (with natural tree regeneration) on the ABLA/XETE, VAGL phase in western Montana. Constancy and coverage data for each community type are shown in appendix A-4. An asterisk indicates hypothesized community types without data. The box at left shows the relationship of conditions and treatment to posttreatment community type, based on our data.

INTERPRETATIONS OF SUCCESSION

Undergrowth.—The VAGL-XETE undergrowth (fig. 8, row 1) persists in mature stands and remains dominant after clearcutting with light to moderate site or slash treatments. VAGL-XETE seems better able to maintain dominance after treatment in northwestern Montana compared to the generally drier areas of west-central Montana (Arno 1979). In a manner similar to that of the PSME/VAGL classification, VAGL decreases as a result of moderately heavy treatments or harsh topographic sites. In these cases, XETE persists and CARU and CAGE increase to form the XETE-CARU community (row 2).

Clearcutting followed by heavy scarification or hot burning treatments usually reduce both VAGL and XETE. In northwestern Montana, these treatments generally resulted in dominance by EPAN (row 5). In west-central Montana extreme scarification—such as on fire lines, major skid trails, and at landings—generally resulted in dense (doghair) lodgepole pine seedlings with depauperate undergrowth (row 4). Otherwise, heavy scarification or hot burning usually resulted in a CARU (and CAGE) community type (row 3). All seral undergrowth communities evidently develop into VAGL-XETE under the influence of a dense pole stage canopy. A possible exception to this return to VAGL-XETE was observed, but not sampled, in some scarified clearcuts that have been heavily grazed for many years and have developed an alternate vegetation dominated by exotic grasses and forbs in place of the native flora.

Trees.—Full stocking of natural regeneration usually required more than 15 years after clearcutting without site or slash treatment or with broadcast burning. In contrast, lodgepole pine regenerated promptly after wildfire, and on scarified sites regeneration was prompt about half the time. In our sample stands, planting (1960's to mid-1970's practices) was usually either superfluous or unsuccessful (Fiedler 1982).

After all treatments, tree succession was dominated by lodgepole pine. By the mature seral forest stage, Douglas-fir becomes a codominant in the overstory. In the old-growth stage, lodgepole pine has essentially died out while subalpine fir has developed into the dominant understory, and it codominates with Douglas-fir in the overstory. Western larch and Engelmann spruce are sometimes secondary components of natural stands. About 40 percent of the mature stands had experienced an understory wildfire prior to 1920; such fires readily killed subalpine fir, but generally did not kill overstory Douglas-fir and larch. Lodgepole pine is able to survive light surface fires.

Hypothesized tree succession scenarios under different disturbance regimes are shown in appendix D-4.

5. *Abies lasiocarpa/Xerophyllum tenax, Vaccinium scoparium* Phase (ABLA/XETE, VASC)

Site characteristics.—This phase is common in the drier, high mountain portions of the study area, particularly in the Sapphire Range east of the Bitterroot Valley. It was found on moderate slopes, usually with south or west aspects, and on ridgetops. Most sites were between 6,400 and 7,300 ft (1 950 and 2 225 m) in elevation except in northwestern Montana, where elevations were about 1,000 ft (300 m) lower. Surface soils tend to be sandy loams, somewhat coarser on the average than those of the VAGL phase. Our site-index and maximum-height data (appendix C) confirm observations of some foresters that the VASC phase is substantially less productive than the VAGL phase. Moreover, the VASC phase appears to be substantially less productive than all six other habitat type phases studied.

Successional classification.—The following key to the successional classification for the ABLA/XETE, VASC phase (fig. 9), should be used to determine the appropriate community type for an unclassified stand.

KEY TO SUCCESSIONAL COMMUNITY TYPES WITHIN THE ABLA/XETE, VASC PHASE

This potential vegetation type is the same as the ABLA/XETE h.t., VASC phase of Pfister and others (1977) as indicated on page 9.

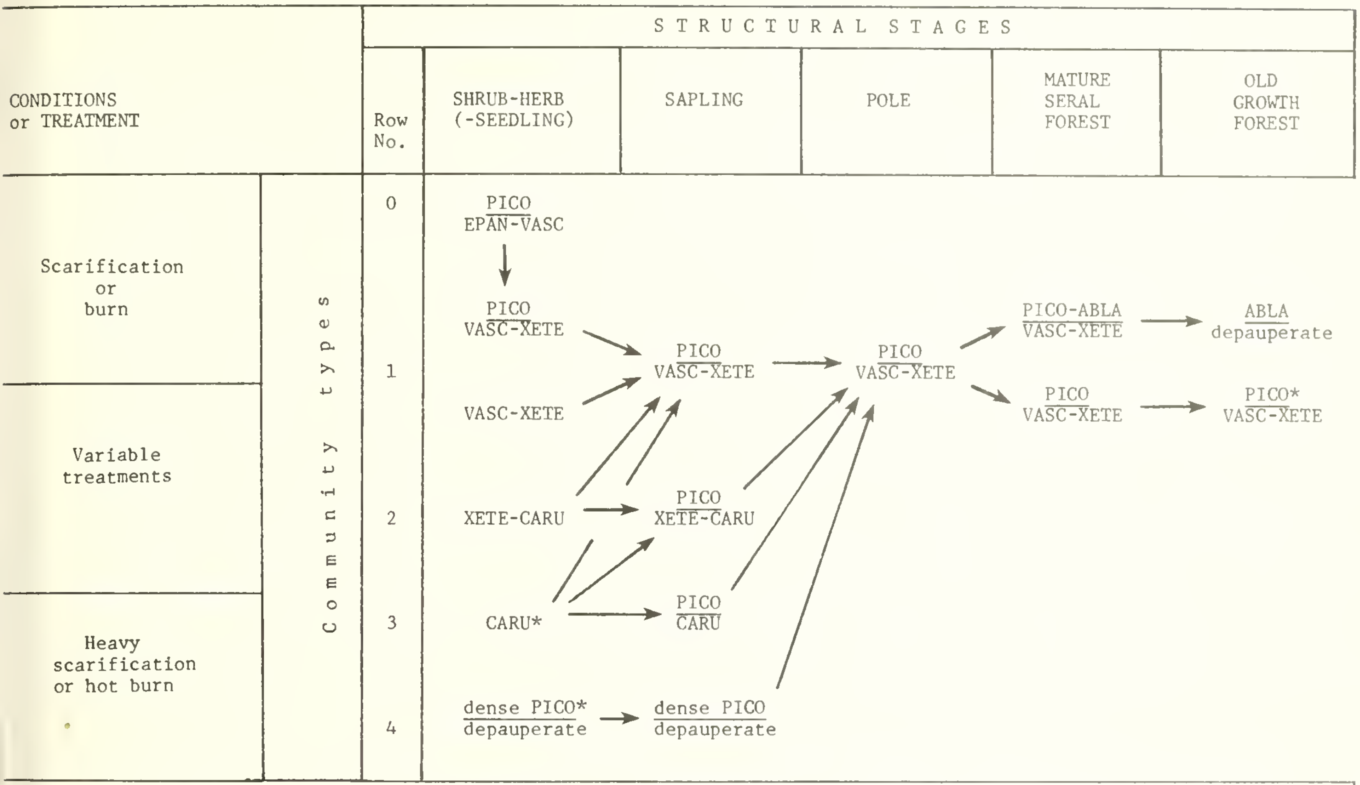
1. Select the most appropriate **community type row number** for the stand in question through use of the undergrowth key below (first priority). Then compare the tree species composition (second priority) with the community type names for that row in figure 9.

Stop at the first requirement that fits:[6]	COMMUNITY TYPE ROW NUMBER (in fig. 9)
a. *Epilobium angustifolium* or *Anaphalis margaritacea* or their combined coverages >25% and *Pinus contorta* seedlings >15% canopy coverage (C.C.)	0
b. *Vaccinium scoparium* >5% C.C.	1
c. *Xerophyllum tenax* >5% C.C.	2
d. *Calamagrostis rubescens* or *Carex geyeri* or their combined coverages >25%	3
e. Not as above; dense *Pinus contorta* seedlings or saplings.	4

2. Select the most appropriate **structural stage** for the stand by comparing it with the stand characteristic values listed in figure 9 for tree canopy coverage, average d.b.h. of dominant trees, stand basal area, and stand age.

3. Inspect appendix A-5, which shows constancy and average canopy coverages of different species in each community type. Is the stand in question compositionally similar to sample stands shown in the indicated community type? If so, it apparently "fits" that community type. If it is dissimilar in terms of major component species, compare it with the other community types listed. It may fit one of those types, or it may not fit this classification at all, which was true of three of the 80 stands (3.7 percent) we sampled.

[6]In stands where undergrowth is obviously depauperate (unusually sparse) because of dense shading or duff accumulations, coverage requirements for the climax species (in this case, community type row 1) can be reduced.



		Stand Characteristics by Structural Stage (Range represents about 90% of the data; extreme values are shown in parentheses)				
		SHRUB-HERB (-SEEDLING)	SAPLING	POLE	MATURE SERAL FOREST	OLD GROWTH FOREST
Range of values from sample stands	Tree canopy coverage percent	T - 15(35)	15 - 80	(30)70 - 85	20 - 65	70
	Average d.b.h. of dominant trees (inches)	0 - 1	1 - 4	6 - 10	8 - 14	15
	Basal area (ft^2/acre)	0 - 2(9)	2 - 35	(20)95 - 216	70 - 150	267
	Stand age (yr)	4 - 22	7 - 41(62)	(26)61 - 120	140 - 220	260
Number of sample stands		22	40	6	8	1

TREATMENT CODES:
NP = Clearcut with no site or slash treatment
MS = Clearcut with mechanical scarification (Dozerpile and burn)
WF = Stand-replacing wildfire

TREES:
ABLA = *Abies lasiocarpa*
PICO = *Pinus contorta*

UNDERGROWTH:
CARU = *Calamagrostis rubescens* (alternate indicator for CARU is *Carex geyeri*)
VASC = *Vaccinium scoparium*
XETE = *Xerophyllum tenax*
EPAN = *Epilobium angustifolium* (alternate indicator for EPAN is *Anaphalis margaritacea*)

Figure 9.—Successional community types (with natural tree regeneration) on the ABLA/XETE, VASC phase in western Montana. Constancy and coverage data for each community type are shown in appendix A-5. An asterisk indicates hypothesized community types without data. The box at left shows the relationship of conditions and treatment to posttreatment community type, based on our data.

INTERPRETATIONS OF SUCCESSION

Undergrowth.—The VASC-XETE undergrowth (fig. 9, row 1) persists in mature stands and generally remains dominant after clearcutting with low-intensity site or slash treatments. With moderately heavy site or slash treatments, VASC decreases dramatically. Sometimes a XETE-CARU (including CAGE) community results (row 2). Heavy scarification kills the XETE, sometimes resulting in a CARU community (row 3). Extreme scarification—such as a fireline, major skid trail, or landing—probably results in a dense lodgepole pine seedling community with depauperate undergrowth (row 4). Stand-replacing wildfire evidently results in dense lodgepole pine seedlings, but with a VASC-XETE undergrowth (row 1). Sometimes EPAN is added as a major component with pine seedlings and VASC (row 0). All the seral undergrowth communities merge toward VASC-XETE at least by the time a pole canopy develops. Virtually all undergrowth may become shaded out if a near-climax subalpine fir stand develops.

Trees.—Natural regeneration of lodgepole pine was generally good on these sites. Tree succession after all treatments is dominated by lodgepole pine, and this species remains the sole dominant in most stands until the mature seral forest stage. In that stage two patterns of overstory development were noted. On some sites (presumably moist ones), subalpine fir essentially replaces lodgepole pine in the old-growth stage. On other sites, subalpine fir remains scattered and lodgepole maintains dominance, evidently regenerating in openings. These latter situations have been recognized in Pfister and others (1977) as "*Pinus contorta* community types."

Two-thirds of the mature stands sampled had experienced a surface fire since their establishment. Usually this had occurred when the stand was in a pole or mature seral forest stage, before heavy overstory mortality and stand breakup.

Hypothesized tree succession scenarios under different disturbance regimes are shown in appendix D-5.

6. *Abies lasiocarpa/Menziesia ferruginea* (ABLA/MEFE), Warm Phase

Site characteristics.—This phase is common throughout the study area on moderate to steep northwest to east exposures, mostly between 5,000 and 6,800 ft (1 525 and 2 075 m) in elevation. Our data include three sample sites that are classified ABLA/CLUN h.t., MEFE phase (Pfister and others 1977), but are near the upper limits of that type and, for our purposes, are seemingly comparable to the other sites. Our site-index and maximum-height data for the warm phase are similar to those of Pfister and others (1977) for the entire habitat type (appendix C). Note that *Picea* site-indexes are based on breast-high age, while other species are based on total age.

Successional classification.—The following key to the successional classification for the ABLA/MEFE warm phase (fig. 10), should be used to determine the appropriate community type for an unclassified stand.

KEY TO SUCCESSIONAL COMMUNITY TYPES WITHIN THE ABLA/MEFE, WARM PHASE

As indicated on page 9, warm phase sites are those where PSME or LAOC are common; additionally VASC is not abundant.

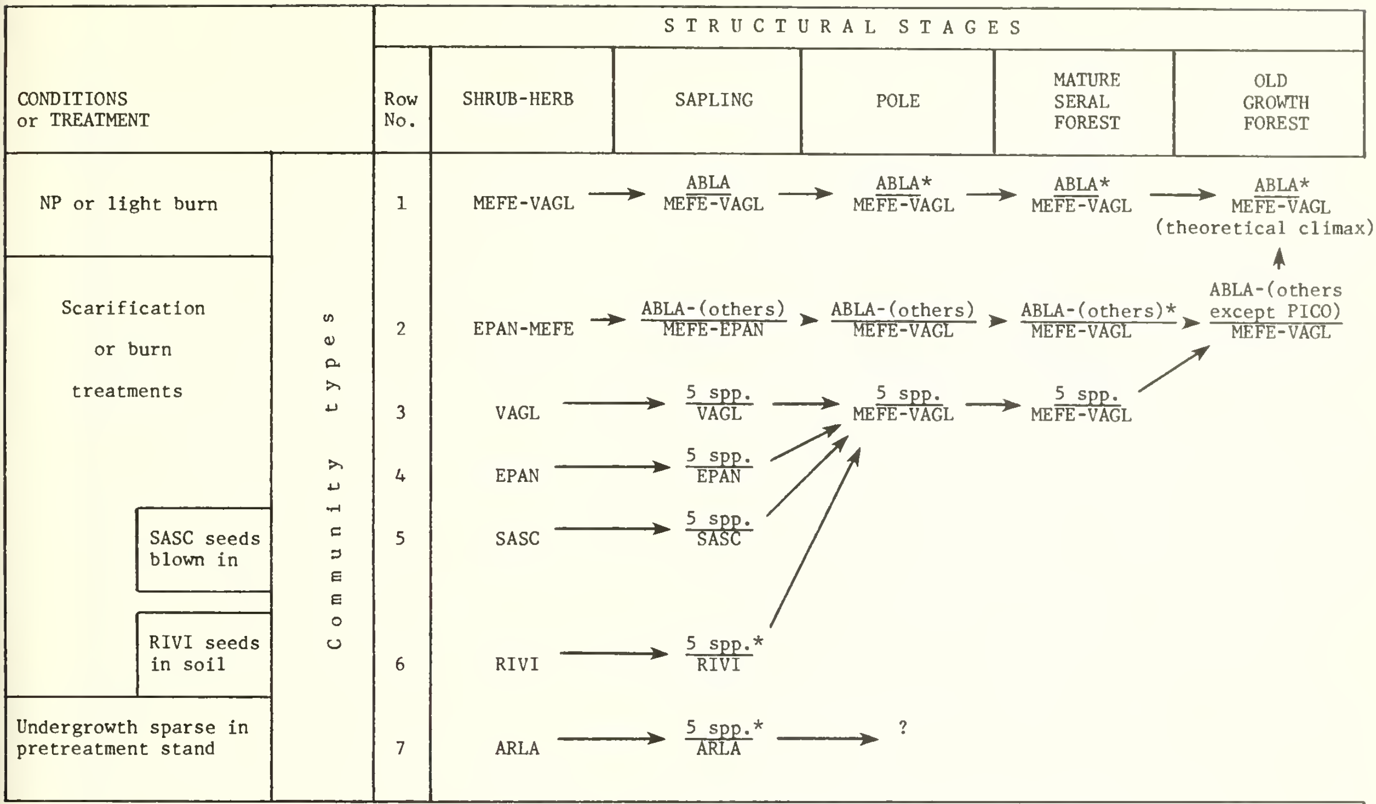
1. Select the most appropriate **community type row number** for the stand in question through use of the undergrowth key below (first priority). Then compare the tree species composition (second priority) with the community type names for that row in figure 10.

	COMMUNITY TYPE ROW NUMBER (in fig. 10)
PART I—applies to shrub-herb and sapling stages	
Stop at the first requirement that fits:[7]	
a. *Menziesia ferruginea* >5% and *Epilobium angustifolium* >5%	2
b. *Menziesia ferruginea* >5%	1
c. *Vaccinium globulare* >5%	3
d. *Salix scouleriana* >5%	5
e. *Ribes viscossimum* >5%	6
f. *Epilobium angustifolium* or *Anaphalis margaritacea* or their combined coverages >25%	4
g. *Arnica latifolia* >25%	7
PART II—applies to pole and older stages	
a. *Abies lasiocarpa* stands; other tree species are poorly represented	1
b. *Abies lasiocarpa* a major overstory component, but other tree species are well represented	2
c. Other species are the major overstory components	3

2. Select the most appropriate **structural stage** for the stand by comparing it with the stand characteristic values listed in figure 10 for tree canopy coverage, average d.b.h. of dominant trees, stand basal area, and stand age.

3. Inspect appendix A-6, which shows constancy and average canopy coverages of different species in each community type. Is the stand in question compositionally similar to sample stands shown in the indicated community type? If so, it apparently "fits" that community type. If it is dissimilar in terms of major component species, compare it with the other community types listed. It may fit one of those types, or it may not fit this classification at all, as was true of four of the 129 stands (3.1 percent) we sampled.

[7]In stands where undergrowth is obviously depauperate (unusually sparse) because of dense shading or duff accumulations, coverage requirements for the climax species (in this case, community type rows 1 and 2) can be reduced.



		Shrub-herb	Sapling	Pole	Mature seral forest	Old growth forest
		Stand Characteristics by Structural Stage (Range represents about 90% of the data; extreme values are shown in parentheses)				
Range of values from sample stands	Tree canopy coverage percent	0 - 15(40)	(10)15 - 70	50 - 90	40 - 70	40 - 75
	Average d.b.h. of dominant trees (inches)	0 - 2	2 - 5	6 - 12	11 - 20	14 - 20
	Basal area (ft^2/acre)	0 - 6	5 - 25	(45)120 - 270	108 - 327	129 - 282
	Stand age (yr)	3 - 22	12 - 33	(31)54 - 80	97 - 260	200 - 300+
Number of sample stands		63	34	8	13	6

TREATMENT CODES:
- NP = Clearcut with no site or slash treatment
- BB = Clearcut with broadcast burning
- MS = Clearcut with mechanical scarification (Dozerpile and burn)
- WF = Stand-replacing wildfire

TREES:
- 5 spp. = All those listed below
- PICO = Pinus contorta
- PIEN = Picea engelmannii
- ABLA = Abies lasiocarpa
- PSME = Pseudotsuga menziesii
- LAOC = Larix occidentalis

UNDERGROWTH:
- MEFE = Menziesia ferruginea
- VAGL = Vaccinium globulare
- EPAN = Epilobium angustifolium
- SASC = Salix scouleriana
- ARLA = Arnica latifolia
- RIVI = Ribes viscosissimum

Figure 10.—Successional community types (with natural tree regeneration) on the ABLA/MEFE warm phase in western Montana. (Warm phase sites are those where Pseudotsuga menziesii *or* Larix occidentalis *is common.) Constancy and coverage data for each community type are showm in appendix A-6. An asterisk indicates hypothesized community types without data. The box at left shows the relationship of conditions and treatment to posttreatment community type, based on our data.*

INTERPRETATIONS OF SUCCESSION

Undergrowth.—The MEFE-VAGL undergrowth (fig. 10, row 1) persists in old stands and generally remains dominant after clearcutting with no site or slash treatment. With clearcutting and broadcast burning or scarification EPAN often joins the MEFE and VAGL (row 2), or MEFE drops out while VAGL remains and is joined by EPAN (row 3). Sometimes VAGL also dies back, leaving an EPAN community type (row 4). A scarification or hot broadcast burn treatment on a site having RIVI seeds in the soil may result in a RIVI community type (row 6), or SASC seeds may be blown in from some distance and result in a SASC community type (row 5). If the undergrowth was sparse in the pretreatment stand and a light treatment was applied, the result may be an ARLA-dominated community type (row 7); evidently MEFE and VAGL were reduced by heavy shading in the pretreatment stand, while ARLA flourished. As the various, young community types mature and reach the pole stage, MEFE-VAGL again becomes the dominant undergrowth.

Trees.—After clearcutting without site or slash treatment, natural regeneration was sometimes retarded. This regeneration consisted primarily of subalpine fir, some of which was old and defective advance regeneration. After broadcast burning and wildfire, sites were usually fully stocked with natural regeneration within 10 years. This was primarily lodgepole pine and secondarily Engelmann spruce. Scarified clearcuts usually regenerated within 15 years; spruce was the most common species, followed by lodgepole pine. Douglas-fir or larch were often successful when planted (1960's to mid-1970's practices).

Where site treatment following clearcutting was light, subalpine fir became the dominant tree from the sapling stage onward (fig. 10, rows 1 and 2). After moderate to heavy treatments, including stand-replacing wildfire, any combination of five tree species—lodgepole pine, Engelmann spruce, subalpine fir, Douglas-fir, and western larch—may dominate through the mature seral forest stage. By the time an old-growth forest has developed, lodgepole pine has died out. In the old-growth stage, subalpine fir dominates the understory and is at least a codominant in the overstory along with veteran spruce, larch, or Douglas-fir. More than 50 percent of the mature stands sampled had experienced an understory wildfire; this would have favored perpetuation of the four seral tree species.

7. *Abies lasiocarpa/Menziesia ferruginea* (ABLA/MEFE), Cold Phase

Site characteristics.—This phase is common near the highest elevations of commercial forest growth on moist sites. It was sampled between 6,000 and 7,300 ft (1 830 and 2 225 m) (down to 5,600 ft [1 710 m] in northwestern Montana) on moderate to steep slopes generally having northwest to east aspects. It sometimes occurred on broad ridgetops. The limited site-index and maximum-height data (appendix C) suggest that this phase is less productive than the warm phase.

Successional classification.—The following key to the successional classification for the ABLA/MEFE cold phase (fig. 11), should be used to determine the appropriate community type for an unclassified stand.

KEY TO SUCCESSIONAL COMMUNITY TYPES WITHIN THE ABLA/MEFE, COLD PHASE

As indicated on page 9, cold phase sites are those where PSME and LAOC are scarce in stands of all ages; additionally VASC is often abundant.

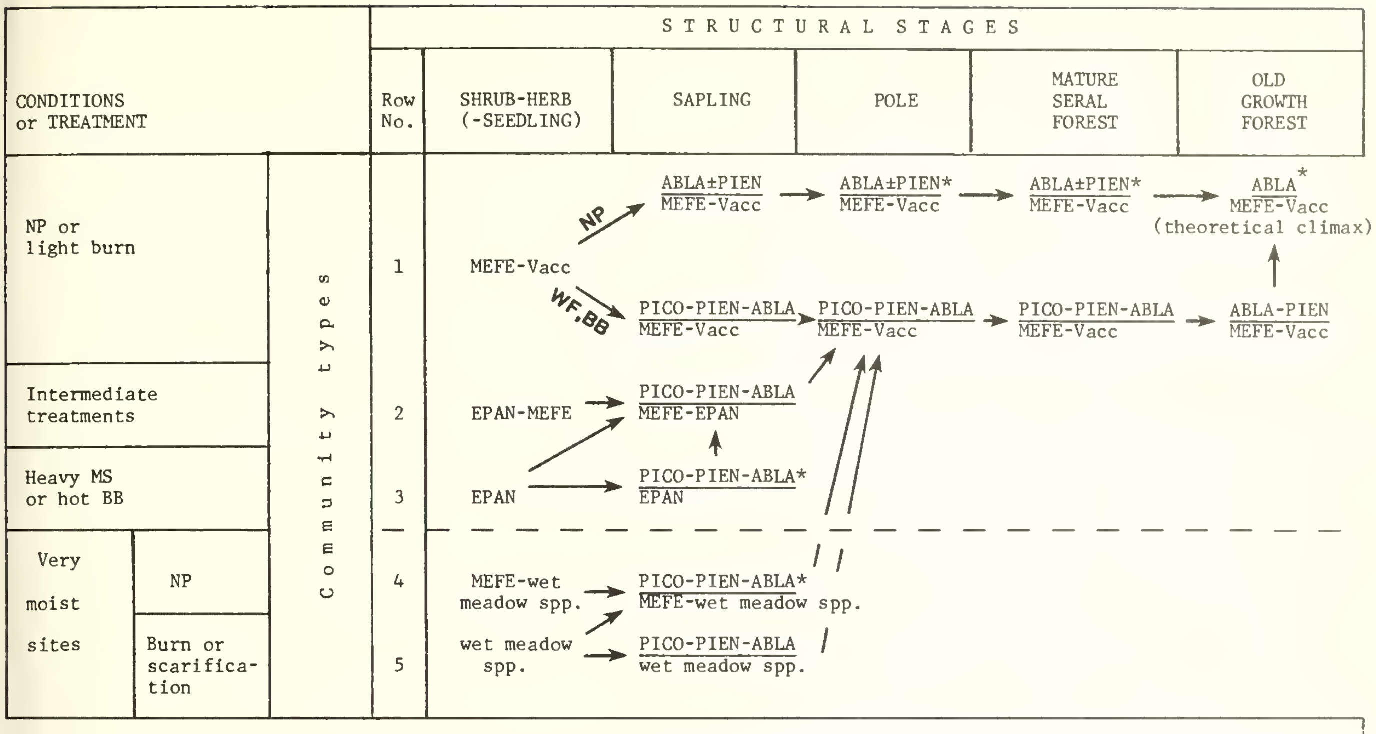
1. Select the most appropriate **community type row number** for the stand in question through use of the undergrowth key below (first priority). Then compare the tree species composition (second priority) with the community type names for that row in figure 11.

Stop at the first requirement that fits:[8]	COMMUNITY TYPE ROW NUMBER (in fig. 11)
a. *Senecio triangularis* or *Veratrum viride* or wet site graminoids (listed on page 36) or their combined coverages >1% and *Menziesia ferruginea* <25% canopy coverage (C.C.)	5
b. *Senecio triangularis* or *Veratrum viride* or wet site graminoids or their combined coverages >1% and *Menziesia ferruginea* >25% C.C.	4
c. *Menziesia ferruginea* >5% and *Epilobium angustifolium* >5% C.C.	2
d. *Menziesia ferruginea* >5% C.C.	1
e. *Epilobium angustifolium* >25% C.C.	3

2. Select the most appropriate **structural stage** for the stand by comparing it with the stand characteristic values listed in figure 11 for tree canopy coverage, average d.b.h. of dominant trees, stand basal area, and stand age.

3. Inspect appendix A-7, which shows constancy and average canopy coverages of different species in each community type. Is the stand in question compositionally similar to sample stands shown in the indicated community type? If so, it apparently "fits" that community type. If it is dissimilar in terms of major component species, compare it with the other community types listed. It may fit one of those types, or it may not fit this classification at all, which was true of three of the 82 stands (3.7 percent) we sampled.

[8] In stands where undergrowth is obviously depauperate (unusually sparse) because of dense shading or duff accumulations, coverage requirements for the climax species (in this case, community type row 1) can be reduced.



Stand Characteristics by Structural Stage
(Range represents about 90% of the data; extreme values are shown in parentheses)

		SHRUB-HERB (-SEEDLING)	SAPLING	POLE	MATURE SERAL FOREST	OLD GROWTH FOREST
Range of values from sample stands	Tree canopy coverage	0 - 15(30)	15 - 50	60 - 80	30 - 60	40 - 60
	Average d.b.h. of dominant trees (inches)	0 - 2	2 - 5	7 - 10	11 - 14(17)	15 - 18
	Basal area (ft^2/acre)	0 - 4	5 - 45	95 - 220	117 - 274	135 - 319
	Stand age (yr)	3 - 25	12 - 29(40)	60 - 115	128 - 200	220 - 300
Number of sample stands		44	17	4	7	7

TREATMENT CODES:
- NP = Clearcut with no site or slash treatment
- BB = Clearcut with broadcast burning
- MS = Clearcut with mechanical scarification (Dozerpile and burn)
- WF = Stand-replacing wildfire
- ± = with or without

TREES:
- ABLA = Abies lasiocarpa
- PICO = Pinus contorta
- PIEN = Picea engelmannii

UNDERGROWTH:
- EPAN = Epilobium angustifolium
- MEFE = Menziesia ferruginea (XETE, Xerophyllum tenax, is a constant associate)
- Vacc = VAGL (Vaccinium globulare), VASC (Vaccinium scoparium), and VAMY (Vaccinium myrtillus).

Figure 11.—Successional community types (with natural tree regeneration) on the ABLA/MEFE cold phase in western Montana. (Cold phase sites are defined as those where Pseudotsuga menziesii *or* Larix occidentalis *are scarce.) Constancy and coverage data for each community type are shown in appendix A-7. An asterisk indicates hypothesized community types without data. The box at left shows the relationship of conditions and treatment to posttreatment community type, based on our data.*

INTREPRETATIONS OF SUCCESSION

Undergrowth.—The MEFE-Vacc (Vacc = VAGL, VASC, and *Vaccinium myrtillus*) undergrowth (fig. 11, row 1) persists in old stands and generally remains dominant after light to moderate clearcutting or fire treatments. On very moist sites within this phase, surface water appears after clearcutting with site preparation, and wet-site associates of *Calamagrostis canadensis* become common (rows 4 and 5). These wet-meadow species include *Calamagrostis canadensis, Cinna latifolia, Deschampsia atropurpurea*, various wet-site *Carex* spp., *Juncus drummondii, Senecio triangularis, Veratrum viride, Trollius laxus, Ligusticum canbyi, Dodecatheon jeffreyi*, and other wet-meadow forbs. These "wet" conditions were not evident in the untreated stands, presumably because the large trees were using the water.

On better drained sites, scarification or hot broadcast burning usually results in an early seral community type dominated by EPAN (row 3). Where the treatment is of intermediate intensity, an EPAN-MEFE community type develops (row 2). All of these seral undergrowth community types (rows 2-5) evidently give way to a MEFE-Vacc undergrowth as the pole stage of conifers begins to develop.

Trees.—Natural regeneration had become fully stocked within 10 years on more than half of the treated sites, including all those burned in wildfires or hot broadcast burns. Clearcuts without site or slash treatments or with light to moderate treatments were usually slow to regenerate and came back primarily to subalpine fir. Successfully regenerated stands were dominated by natural lodgepole pine with lesser amounts of subalpine fir and Engelmann spruce. Planting (1960's to mid-1970's practices) of spruce was partially successful.

After all treatments except clearcutting without site or slash preparation, lodgepole pine evidently develops as the overstory dominant and retains that position until the mature seral forest stage. By the old-growth stage, however, lodgepole pine dies out, leaving subalpine fir and Engelmann spruce as overstory dominants, with subalpine fir forming the understory. Spruce is a large, long-lived seral tree that depends primarily on infrequent disturbances to reestablish it in appreciable quantities. Only one of the 14 mature and old-growth sample stands showed evidence of having had an understory wildfire since stand establishment; apparently stand-replacing fires recycled these stands at long intervals.

SPECIES RESPONSE

This summary reports apparent responses of individual undergrowth species to the different kinds of treatments recorded during the current study and makes no attempt to correlate them with literature on plant response such as Fischer and Clayton (1983), Volland and Dell (1981), and Stickney (1980). Remember that our response measurements were generally made 4 to 20 years after treatment. The indicated response describes changes from conditions in the mature communities.

Shrubs

Acer glabrum is common in both phases of PSME/PHMA. It showed little change after most treatments, but generally increased after wildfire (presumably from root-crown sprouting) and maintained greater canopy coverage in the form of very tall shrubs growing among pole-stage conifers. Browsing by big game may locally prevent full development of this shrub.

Alnus sinuata is common, as a minor stand component, only in the ABLA/MEFE warm phase. It showed little change after most treatments, but increased moderately after WF and BB (treatment codes are explained in fig. 6). Along the cuts, fills, and beds of roads and some other "extreme scarification" microsites, it sometimes increases dramatically (from seeding) to form dense strips.

Amelanchier alnifolia is ubiquitous, and occasionally a major component, in PSME/PHMA. It generally increased (presumably from root crowns) after WF and other treatments, although this response was sometimes delayed a decade or more. In some areas, big game browsing pressure may be sufficient to stifle increases. Scarification treatments produced little change or possibly a decrease; this may result from destruction of root crowns. This species maintains relatively great canopy coverage as very tall shrubs growing among pole-stage conifers. It was sometimes common in PSME/VAGL sites, but exhibited little change after all treatments there.

Ceanothus sanguineus occasionally becomes abundant after burning treatments on north aspects in the PSME/PHMA moist phase in the western portion of northwestern Montana. This species becomes widespread westward in northern Idaho, where it occurs on several habitat types. It is ecologically similar to the more ubiquitous *Ceanothus velutinus*.

Ceanothus velutinus is essentially absent in mature seral and old-growth stages, but often became a stand component after BB or WF treatments in PSME/PHMA dry phase, PSME/VAGL, and occasionally PSME/PHMA moist phase. The species is clearly intolerant of overstory shade and died out by the time the pole stage was reached. Response evidently resulted from heat treatment of seed stored in the surface soil. The species failed to appear after NP and only small amounts resulted from dozer-pile and burn treatments.

Lonicera utahensis is most common in the ABLA/MEFE warm phase. It showed little change after all treatments and was occasionally browsed in the young stands.

Menziesia ferruginea is a major undergrowth component throughout the ABLA/MEFE h.t., and its coverage declined following all treatments except NP, where it remained steady. We found no evidence that BB or WF leads to a MEFE "brushfield" in either phase of ABLA/MEFE h.t. Scarification treatments resulted in marked declines. Following WF, recovery to predisturbance levels appears to require about 30 to 50 years.

Pachistima myrsinites was occasionally common on sites in the ABLA/MEFE warm phase, ABLA/XETE, VAGL phase; and PSME/VAGL h.t. It showed little change after all treatments.

Physocarpus malvaceus is the major shrub in the PSME/PHMA h.t. It decreased somewhat in response to heavy scarification, and a modest decrease was noted after BB on the dry phase. Little change occurred after NP or WF.

Prunus virginiana occasionally became common following BB, WF, or NP treatments on the PSME/PHMA dry phase. It was very scarce in the untreated stands.

Ribes viscosissimum occasionally became common following scarification treatments in the ABLA/MEFE warm phase. It was scarce in untreated stands.

Rubus parviflorus was occasionally common in mature stands in the ABLA/MEFE warm phase, and it often increased modestly after scarification treatments. It showed little change following other treatments.

Salix scouleriana was often a minor component of stands in the PSME/PHMA, PSME/VAGL, and the warm phase of ABLA/MEFE. In PSME/PHMA it increased after all treatments, and the increase was most pronounced following WF. In PSME/VAGL, little change or modest increase was noted after all treatments. In the ABLA/MEFE warm phase, a strong increase was recorded after WF, modest increase after scarification, and generally little change after BB and NP treatments. The larger increases evidently resulted from establishment of wind-transported seed. Once this species becomes well established (in the absence of severe big game browsing) it grows very tall and persists well into the pole stage.

Spiraea betulifolia is a major component of many stands in PSME/PHMA and a minor component of most stands in PSME/VAGL and ABLA/XETE. It increased rather consistently after scarification treatments. After other treatments it showed little change or modest increases.

Symphoricarpos albus is often a major component of stands in the dry phase of PSME/PHMA and is often a minor component in the moist phase. In the dry phase, it generally increased after NP, BB, and MS treatments, but showed little change after WF. In the moist phase, it exhibited little change after NP and MS; there were few data for other treatments.

Vaccinium globulare is a major undergrowth component of most pole-stage or older stands in the PSME/VAGL, ABLA/XETE, VAGL phase, and ABLA/MEFE h.t. It is a minor component of most ABLA/XETE, VASC phase stands. In all habitat type phases, it decreased strongly following scarification treatments and did not recover for about 20 years. On the relatively warm and dry PSME/VAGL h.t., it decreased strongly following all treatments. On ABLA/XETE, VAGL phase, it decreased modestly after NP and strongly after BB and WF, but apparently begins to recover sooner after WF than after scarification. On ABLA/MEFE h.t., it showed little or no decrease after NP and light to moderate BB; it decreased strongly after relatively hot BB and WF, but recovered after about 15 years. After all treatments, a few stunted stems would appear around the edges of rocks or stumps. These evidently were sprouts from surviving rhizomes. As a canopy of saplings developed, this shrub would expand beneath it.

Vaccinium scoparium is a major undergrowth component on the ABLA/MEFE, VASC phase; the ABLA/XETE, VASC phase; and often the ABLA/XETE, VAGL phase. This species had a response similar to that of *Vaccinium globulare*. It decreased strongly after scarification treatments, and less dramatically after most BB, WF, and NP treatments.

Subshrubs

Arctostaphylos uva-ursi is a ground layer associate of CARU and CAGE that was often common on the moist phase of PSME/PHMA and on the PSME/VAGL h.t. It increased strongly after NP and showed little or variable change following other treatments. Its root crown is apparently easily killed by fire or scraping, but any surviving plant parts (and seed regeneration) may allow a rather rapid recovery.

Berberis repens is often a minor associate of stands in the PSME/PHMA, PSME/VAGL, and ABLA/XETE, VAGL phase. It showed little change following treatments, except for occasional decreases after scarification.

Linnaea borealis is occasionally common in the PSME/PHMA moist phase and in the ABLA/MEFE warm phase. Its perenneating organs are near the surface and are evidently vulnerable to fire and scarification (Fischer and Clayton 1983). On PSME/PHMA it generally decreases following all treatments. On ABLA/MEFE it showed variable changes following all treatments.

Graminoids

Calamagrostis rubescens is a major component of the undergrowth in both phases of PSME/PHMA and in PSME/VAGL. It is a minor component in both phases of ABLA/XETE. On the PSME/PHMA moist phase, it showed little change after NP, but decreased after BB and MS. On the dry phase it showed little or variable changes after treatments. On PSME/VAGL it generally increased after NP or light BB, while it was little changed following hot BB or scarification. (It decreased on the youngest WF stand pair, but this was related to development of an extremely dense sapling stand.) Although it is only a minor component in the ABLA/XETE h.t., the species tended to increase strongly after all treatments, except that on the VAGL phase it showed little change after scarification.

Carex geyeri is a major component of many stands in the dry phase of PSME/PHMA and is a common minor component of the PSME/PHMA moist phase, the PSME/VAGL h.t., and the ABLA/XETE h.t. On the PSME/PHMA dry phase it showed a decrease 5 years after BB and WF, and little or variable changes following other treatments. In the other habitat types

and phases, it generally increased after NP, light BB, or scarification. It showed variable changes after hot BB and WF.

Carex rossii is often present in small amounts on untreated stands in the ABLA/XETE and the cold phase of ABLA/MEFE. It increased after all treatments, except occasionally after NP, and it increased strongly after scarification. ***Carex concinnoides*** showed a similar response on both phases of ABLA/XETE h.t.

Forbs

Anaphalis margaritacea is a native species that is rare in mature stands, but colonizes (from wind-transported seed) many of the treated sites in the PSME/VAGL; ABLA/XETE, VAGL phase; and ABLA/MEFE h.t.'s. It becomes common most often following scarification treatments. ***Achillea millefolium*** has a similar response pattern.

Antennaria racemosa is often a minor component of stands on the PSME/PHMA and PSME/VAGL h.t.'s. It showed little change after NP. On the dry phase of PSME/PHMA and on PSME/VAGL, it generally decreased after other treatments, while on the moist phase it showed little change.

Arnica latifolia is often a minor component of the undergrowth on PSME/VAGL and ABLA/XETE, VAGL phase, and it decreased following all stand-removal treatments. It is often a major component of the warm phase of ABLA/MEFE and a minor component of the cold phase. On both phases it showed variable changes following all treatments. It seems to be more tolerant of stand-removing treatments on the ABLA/MEFE h.t., presumably because of moist site conditions.

Aster conspicuus was often a minor component on the PSME/PHMA moist phase and PSME/VAGL h.t. It appeared to increase after NP and showed little change after other treatments.

Chimaphila umbellata, Goodyera oblongifolia, and ***Pyrola secunda*** are small, wintergreen herbs that are widespread in mature stands in these habitat types, but seldom contribute appreciably to undergrowth canopy coverage. All three species essentially disappeared following stand removal treatments, except that some quantity survived after NP. All three species (and probably other wintergreen forbs) return with the development of a new overstory canopy.

Epilobium angustifolium is a wind-seeded native colonizer that became a component of treated stands, other than NP, on the PSME/VAGL h.t. and ABLA/XETE, VAGL phase. It often became a major component on both phases of ABLA/MEFE after scarification, WF, or hot BB.

Fragaria vesca and ***Fragaria virginiana*** form a minor component of the ground cover on PSME/PHMA and PSME/VAGL h.t.'s. They showed little change in response to treatments.

Hedysarum boreale and ***Hedysarum occidentale*** are present in small amounts in a few mature stands in the PSME/VAGL and both phases of ABLA/XETE h.t. These species increased strongly following all treatments in those stands.

Iliamna rivularis is a short-lived seral species that occasionally became well represented after WF or hot BB treatments in the PSME/PHMA dry phase. It evidently regenerated from seed stored in the soil.

Senecio triangularis is a wet-site forb that was often present in small amounts in mature stands in the ABLA/MEFE cold phase. It generally increased with treatments other than NP.

Xerophyllum tenax is a major undergrowth component on the PSME/VAGL, ABLA/XETE, and cold phase of ABLA/MEFE. It is usually a minor component on the warm phase of ABLA/MEFE. On all habitat types, it decreased strongly after scarification and evidently requires 25 years or more to recover. It decreased after WF or relatively hot BB on all habitat types, except the VASC phase of ABLA/XETE, where it showed little change. It showed little or variable change after NP or light BB, except on the ABLA/XETE, VASC phase where it increased, and PSME/VAGL where it decreased. Thus, it was most vulnerable on PSME/VAGL, decreasing after all treatments. In contrast, it was least vulnerable on the ABLA/XETE, VASC phase, where it decreased only after scarification.

REFERENCES

Arno, S. F. The historical role of fire on the Bitterroot National Forest. Research Paper INT-187. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1976. 29 p.

Arno, Stephen F. Forest regions of Montana. Research Paper INT-218. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1979. 39 p.

Arno, S. F. Forest fire history in the Northern Rockies. Journal of Forestry. 78(8): 460-465; 1980.

Arno, S. F.; Sneck (Davis), K. M. A method for determining fire history in coniferous forests of the Mountain West. General Technical Report INT-42. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1977. 28 p.

Cholewa, A. F.; Johnson, F. D. Secondary succession in the *Pseudotsuga menziesii/Physocarpus malvaceus* association. Northwest Science. 57: 273-282; 1983.

Daubenmire, R. A comparison of approaches to the mapping of forest land for intensive management. Forestry Chronicle. 49(2): 87-91; 1973.

Fiedler, C. E. Regeneration of clearcuts in four habitat types in western Montana. In: Baumgartner, D. M., ed. Site preparation and fuels management on steep terrain: symposium proceedings; 1982 February 15-17; Spokane, WA. Pullman, WA: Washington State University, Cooperative Extension; 1982: 139-147.

Fischer, W. C.; Clayton, B. D. Fire ecology of Montana forest habitat types east of the Continental Divide. General Technical Report INT-141. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1983. 83 p.

Gruell, George E.; Schmidt, Wyman C.; Arno, Stephen F.; Reich, William J. Seventy years of vegetal change in a managed ponderosa pine forest in western Montana—implications for resource management. General Technical Report INT-130. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1982. 42 p.

Hann, W. J. A taxonomy for classification of seral vegetation of selected habitat types in western Montana. Moscow, ID: University of Idaho; 1982. 235 p. Ph.D. dissertation.

Keane, R. E. Evaluation of a successional classification system. Unpublished cooperative report on file at: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station, Northern Forest Fire Laboratory, Drawer G, Missoula, MT; 1983. 25 p.

Lyon, L. J.; Stickney, P. F. Early vegetal succession following large northern Rocky Mountain wildfires. Proceedings, Tall Timbers Fire Ecology Conference. 14: 355-375; 1976.

Mueller-Dombois, D.; Ellenberg, H. Aims and methods of vegetation ecology. New York: John Wiley and Sons; 1974. 547 p.

Nimlos, T. J. Zonal great soil groups in western Montana. Montana Academy of Science Proceedings. 23: 3-13; 1963.

Pfister, R. D.; Kovalchik, B. L.; Arno, S. F.; Presby, R. C. Forest habitat types of Montana. General Technical Report INT-34. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1977. 174 p.

Pfister, R. E.; Arno, S. F. Classifying forest habitat types based on potential climax vegetation. Forest Science. 26(1): 52-70; 1980.

Steele, R. An approach to classifying seral vegetation within habitat types. Northwest Science. 58: 29-39; 1984.

Stickney, P. F. Data base for post-fire succession, first 6 to 9 years, in Montana larch-fir forests. General Technical Report INT-62. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1980. 133 p.

Stickney, P. F. First decade plant succession following the Sundance Forest Fire, northern Idaho. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; [in preparation].

Thomas, J. W., tech. ed. Wildlife habitats in managed forests: the Blue Mountains of Oregon and Washington. Agriculture Handbook 553. Washington, DC: U.S. Department of Agriculture, Forest Service; 1979. 512 p.

U.S. Department of Agriculture, Soil Conservation Service. Soil taxonomy. Agriculture Handbook 436. Washington, DC: U.S. Department of Agriculture, Forest Service; 1975. 754 p.

Volland, L. A.; Dell, J. D. Fire effects on Pacific Northwest forest and range vegetation. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region; 1981. 23 p.

Zamora, B. A. Secondary succession on broadcast-burned clearcuts of the *Abies grandis-Pachistima myrsinites* habitat type in north-central Idaho. Pullman, WA: Washington State University; 1975. 117 p. Ph.D dissertation.

APPENDIX A-1.—CONSTANCY* AND AVERAGE CANOPY COVERAGE (PERCENT) OF IMPORTANT PLANTS IN EACH COMMUNITY TYPE OF THE PSME/PHMA, DRY PHASE

(Abbreviated scientific names of plants are listed below; full names are listed in appendix B.)

STRUCTUAL STAGE	SHRUB-HERB				SAPLING				POLE			MATURE SERAL FOREST			
Community Type	PHMA	PHMA-CARU	PHMA-AMAL	CEVE-PHMA	PSME/PHMA	PSME/PHMA-CARU	PSME/PHMA-AMAL	PSME/CEVE-PHMA	PSME/PHMA	PSME/PHMA-CARU	PSME/PHMA-AMAL	PSME/PHMA	PSME/PHMA-CARU	PSME/PHMA-AMAL	PSME-PIPO/PHMA-
Number of Plots	13	20	13	17	2	12	7	6	6	7	10	4	8	5	15
TREE SPECIES ********															
6 LAROCC	1(T)	+(T)	2(T)	-( )	-( )	-( )	1(T)	-( )	2(T)	3(3)	2(T)	-( )	1(T)	10(1)	1(8)
10 PINCON	-( )	2(T)	2(T)	2(5)	-( )	4(2)	1(63)	2(T)	2(T)	4(14)	3(3)	2(T)	1(3)	4(T)	-( )
13 PINPON	7(2)	5(4)	7(3)	5(T)	10(20)	7(26)	9(24)	10(18)	10(3)	7(15)	8(11)	10(1)	6(T)	10(1)	10(26)
14 POPTRE	2(T)	2(4)	-( )	1(T)	5(T)	3(1)	-( )	-( )	-( )	-( )	-( )	-( )	-( )	-( )	-( )
16 PSEMEN	7(2)	9(5)	8(7)	8(T)	10(9)	10(30)	10(27)	10(27)	10(70)	10(65)	10(64)	10(44)	10(62)	10(48)	10(30)
SHRUB SPECIES ********															
102 ACEGLA	6(1)	3(1)	7(8)	3(7)	5(3)	1(T)	6(8)	3(9)	7(T)	4(2)	7(20)	10(5)	5(5)	10(9)	1(3)
105 AMEALN	10(5)	8(4)	10(20)	9(5)	10(8)	6(T)	10(14)	10(16)	7(5)	10(6)	10(16)	7(2)	10(4)	10(36)	10(4)
198 CEASAN	-( )	+(T)	2(8)	-( )	-( )	-( )	-( )	2(15)	-( )	-( )	-( )	-( )	-( )	-( )	-( )
107 CEAVEL	2(1)	2(T)	4(2)	10(41)	-( )	-( )	-( )	10(54)	-( )	4(1)	5(T)	-( )	2(2)	-( )	1(T)
111 HOLDIS	-( )	1(2)	2(15)	2(10)	-( )	-( )	-( )	-( )	-( )	-( )	1(T)	-( )	1(T)	4(19)	-( )
115 LONUTA	3(T)	3(1)	4(2)	3(T)	-( )	4(4)	4(1)	-( )	-( )	-( )	2(8)	5(T)	2(T)	6(T)	1(T)
119 PHILEW	1(T)	-( )	-( )	1(8)	-( )	-( )	1(T)	-( )	-( )	-( )	-( )	-( )	-( )	-( )	-( )
122 PHYMAL	10(46)	10(37)	9(26)	10(23)	10(39)	10(17)	10(12)	10(28)	10(38)	10(32)	10(38)	10(62)	10(41)	6(31)	10(45)
123 PRUEMA	-( )	+(T)	1(3)	1(3)	-( )	-( )	-( )	-( )	-( )	1(T)	1(T)	-( )	-( )	-( )	1(T)
124 PRUVIR	2(T)	1(2)	4(7)	3(2)	-( )	-( )	-( )	3(T)	2(T)	1(3)	2(8)	2(T)	2(T)	-( )	2(T)
125 PURTRI	-( )	-( )	2(6)	-( )	-( )	-( )	1(T)	-( )	-( )	-( )	-( )	-( )	-( )	-( )	1(T)
128 RIBCER	1(T)	+(3)	-( )	-( )	-( )	6(T)	-( )	-( )	-( )	-( )	-( )	-( )	1(T)	-( )	-( )
130 RIBLAC	-( )	1(T)	1(3)	1(T)	-( )	3(2)	1(T)	-( )	-( )	-( )	1(T)	-( )	-( )	-( )	-( )
131 RIBVIS	2(T)	2(7)	3(8)	5(2)	10(2)	8(1)	1(15)	3(T)	-( )	1(T)	1(T)	2(T)	1(T)	4(T)	1(T)
132 ROSACI	2(1)	2(T)	2(1)	3(4)	-( )	4(T)	3(T)	3(T)	3(2)	-( )	-( )	-( )	-( )	4(T)	1(T)
133 ROSGYM	2(1)	3(T)	6(3)	4(T)	5(3)	3(1)	6(T)	5(T)	-( )	3(2)	7(T)	2(T)	1(T)	10(9)	1(T)
134 ROSWOO	1(T)	+(T)	-( )	1(T)	-( )	-( )	1(T)	2(T)	-( )	-( )	-( )	2(T)	-( )	-( )	1(T)
136 RUBPAR	-( )	1(1)	3(1)	2(T)	5(T)	2(T)	3(9)	2(T)	-( )	-( )	2(T)	-( )	-( )	6(T)	-( )
137 SALSCO	5(T)	5(1)	6(15)	7(4)	10(3)	6(4)	10(15)	3(3)	2(T)	3(3)	7(8)	2(T)	2(T)	6(1)	1(T)
164 SAMCER	-( )	1(T)	1(T)	-( )	-( )	-( )	-( )	2(T)	2(T)	1(T)	2(T)	-( )	1(T)	-( )	-( )
139 SHECAN	-( )	+(T)	3(1)	1(T)	5(T)	4(T)	4(T)	-( )	-( )	-( )	-( )	2(T)	-( )	2(T)	1(T)
142 SPIBET	9(17)	7(11)	10(10)	10(8)	10(2)	10(12)	10(10)	7(5)	7(5)	7(8)	8(3)	10(19)	6(2)	10(17)	7(5)
143 SYMALB	8(15)	8(12)	9(10)	8(10)	10(20)	9(14)	10(13)	7(8)	8(4)	7(14)	9(5)	5(9)	5(12)	10(9)	9(10)
163 SYMORE	2(5)	1(2)	2(2)	2(5)	-( )	2(1)	-( )	2(T)	2(3)	-( )	-( )	2(3)	-( )	-( )	1(T)
146 VACGLO	2(3)	2(5)	5(11)	3(T)	-( )	3(4)	4(5)	2(T)	2(3)	1(T)	1(3)	-( )	1(3)	6(T)	-( )
SUBSHRUB SPECIES *******															
201 ARCUVA	2(T)	4(5)	5(T)	2(8)	10(8)	8(15)	9(3)	8(1)	2(T)	3(2)	2(T)	2(3)	1(3)	4(T)	3(1)
203 BERREP	6(T)	7(1)	8(3)	8(1)	-( )	6(7)	3(T)	7(5)	8(7)	7(7)	8(T)	7(T)	9(2)	8(T)	7(2)
204 CLECOL	3(T)	2(1)	2(T)	1(T)	-( )	2(1)	1(T)	-( )	2(T)	-( )	4(T)	5(T)	2(T)	8(T)	2(T)
206 LINBOR	2(2)	1(3)	4(8)	-( )	5(T)	3(12)	1(3)	-( )	-( )	-( )	2(T)	-( )	-( )	6(T)	1(15)
GRAMINOIDS ************															
301 AGRSPI	2(T)	2(7)	4(9)	2(8)	-( )	2(T)	1(T)	3(2)	-( )	1(3)	3(T)	7(T)	6(12)	-( )	3(5)
303 BROCAR	1(T)	2(2)	1(T)	2(T)	-( )	-( )	-( )	3(T)	2(T)	4(T)	-( )	-( )	4(T)	2(T)	-( )
307 CALRUB	9(6)	9(33)	9(16)	9(11)	10(15)	10(40)	10(20)	10(9)	10(7)	10(26)	9(13)	5(9)	10(26)	10(38)	9(46)
308 CARCON	5(T)	5(2)	6(1)	3(T)	-( )	7(T)	6(5)	3(2)	-( )	3(2)	1(3)	5(T)	4(1)	8(T)	1(T)
309 CARGEY	9(6)	9(19)	8(15)	10(11)	10(3)	10(9)	9(21)	10(26)	7(5)	7(26)	9(29)	10(1)	10(41)	8(2)	9(23)
[illegible]	[illegible]	[illegible]	[illegible]	4(T)	-( )	-( )	-( )	-( )	-( )	1(T)	3(T)	-( )	1(T)	2(T)	1(T)

316 ELYGLA	1(3)	+(T)	2(T)	-( )	-( )	-( )	-( )	3(T)	2(T)	-( )	1(T)	-( )	1(3)	2(T)	1(T)
317 FESIDA	1(T)	2(T)	3(5)	1(T)	-( )	-( )	-( )	-( )	-( )	1(3)	1(T)	-( )	1(T)	-( )	1(T)
318 FESOCC	3(T)	1(1)	2(T)	1(T)	-( )	1(T)	1(3)	-( )	-( )	3(T)	4(T)	2(T)	7(T)	4(T)	1(T)
319 FESSCA	2(2)	1(T)	1(T)	2(1)	-( )	1(T)	1(T)	-( )	-( )	1(3)	-( )	-( )	-( )	-( )	2(1)
396 POACOM	-( )	+(3)	-( )	-( )	-( )	-( )	1(3)	2(T)	-( )	-( )	-( )	-( )	-( )	-( )	-( )
331 POANER	-( )	2(5)	-( )	-( )	5(T)	2(T)	-( )	-( )	-( )	1(T)	-( )	2(T)	1(T)	-( )	2(T)
PERENNIAL FORBS	*******														
401 ACHMIL	8(T)	7(T)	5(1)	7(T)	5(T)	7(2)	7(T)	7(1)	2(T)	7(T)	2(T)	-( )	7(T)	-( )	7(T)
404 ALLCER	4(T)	2(T)	2(T)	1(T)	-( )	-( )	3(T)	2(T)	2(T)	6(T)	2(T)	2(T)	2(T)	-( )	6(T)
405 ANAMAR	-( )	-( )	2(2)	2(1)	5(T)	-( )	-( )	2(T)	-( )	-( )	-( )	-( )	-( )	-( )	-( )
414 ANTMIC	1(T)	+(T)	1(T)	1(T)	5(T)	3(T)	1(T)	2(T)	-( )	1(T)	1(T)	-( )	1(T)	-( )	1(T)
413 ANTRAC	6(2)	8(3)	4(T)	2(T)	10(3)	7(5)	9(T)	2(T)	2(T)	4(5)	3(5)	-( )	7(3)	8(T)	7(4)
415 APOAND	-( )	1(T)	3(8)	2(1)	-( )	-( )	1(T)	2(T)	-( )	-( )	1(T)	-( )	-( )	-( )	1(T)
421 ARNCOR	5(T)	4(1)	2(T)	2(T)	5(3)	6(2)	4(T)	2(T)	7(2)	6(1)	1(3)	7(1)	1(3)	4(T)	3(2)
422 ARNLAT	3(1)	3(3)	5(4)	2(1)	10(3)	9(1)	3(2)	2(T)	5(T)	3(9)	-( )	-( )	-( )	-( )	-( )
426 ASTCON	5(4)	7(9)	6(2)	4(3)	5(38)	9(14)	6(4)	5(2)	-( )	10(3)	5(T)	2(T)	4(T)	10(T)	5(T)
428 ASTLAE	-( )	1(T)	2(T)	1(T)	-( )	1(T)	3(T)	5(T)	2(T)	1(T)	-( )	-( )	-( )	4(T)	1(T)
429 ASTCAN	-( )	-( )	-( )	1(15)	-( )	1(T)	-( )	-( )	-( )	-( )	-( )	-( )	-( )	-( )	-( )
431 BALSAG	1(T)	3(10)	4(2)	3(T)	5(T)	1(T)	1(T)	3(T)	3(T)	4(1)	5(T)	5(T)	6(1)	-( )	5(5)
436 CAMROT	1(T)	-( )	1(T)	1(T)	-( )	-( )	-( )	3(T)	-( )	3(T)	2(T)	-( )	1(T)	-( )	1(T)
438 CASMIN	-( )	2(1)	2(T)	2(T)	-( )	4(T)	1(T)	-( )	2(T)	-( )	-( )	-( )	-( )	-( )	1(T)
442 CHIUMB	-( )	+(T)	-( )	-( )	-( )	-( )	4(T)	-( )	-( )	1(T)	-( )	2(T)	-( )	6(T)	-( )
597 CIRUND	-( )	2(1)	-( )	1(3)	-( )	2(T)	1(T)	-( )	-( )	-( )	-( )	-( )	-( )	-( )	-( )
455 DISTRA	1(T)	1(T)	2(T)	-( )	-( )	1(T)	1(T)	-( )	2(T)	1(T)	3(T)	5(2)	1(T)	6(T)	2(T)
459 EPIANG	5(3)	6(1)	5(2)	5(2)	5(3)	7(3)	6(T)	5(1)	-( )	-( )	2(T)	5(T)	1(T)	2(T)	-( )
464 ERYGRA	3(T)	2(T)	2(T)	2(T)	-( )	5(T)	3(T)	2(T)	5(T)	1(T)	6(T)	2(T)	6(T)	-( )	5(T)
465 FRAVES	7(1)	8(4)	9(2)	6(3)	10(3)	10(9)	7(2)	8(2)	7(T)	9(1)	7(T)	7(T)	10(1)	10(T)	8(1)
466 FRAVIR	5(3)	7(T)	6(T)	6(1)	-( )	3(T)	4(1)	10(T)	7(T)	6(1)	8(T)	5(T)	7(T)	8(T)	6(1)
476 GOOOBL	-( )	-( )	-( )	-( )	-( )	1(T)	3(T)	-( )	5(T)	1(T)	3(1)	2(T)	4(T)	8(T)	2(T)
482 HEUCYL	2(T)	3(T)	2(T)	1(T)	-( )	-( )	3(T)	-( )	-( )	3(T)	1(T)	-( )	4(T)	-( )	3(T)
483 HIEALB	2(T)	2(T)	2(T)	4(T)	5(T)	2(1)	3(T)	3(T)	7(T)	3(T)	2(T)	2(T)	1(T)	-( )	2(T)
833 ILLRIV	2(5)	+(T)	2(9)	1(3)	-( )	-( )	-( )	-( )	-( )	-( )	-( )	-( )	-( )	-( )	-( )
495 LITRUD	-( )	3(T)	2(T)	1(T)	5(T)	2(T)	-( )	3(T)	-( )	-( )	1(T)	-( )	2(T)	-( )	2(T)
499 LUPINU	2(T)	4(2)	1(3)	1(T)	5(3)	4(1)	1(T)	2(T)	2(T)	3(T)	1(T)	-( )	5(4)	2(T)	7(4)
502 MITSTA	2(2)	+(T)	1(T)	2(T)	-( )	-( )	1(T)	-( )	2(T)	1(T)	1(T)	2(T)	2(T)	-( )	1(T)
505 OSMCHI	1(3)	-( )	-( )	-( )	-( )	-( )	1(T)	2(T)	3(T)	1(T)	1(T)	-( )	1(T)	4(T)	1(T)
508 PEDCON	-( )	1(T)	1(T)	-( )	-( )	6(T)	-( )	-( )	-( )	-( )	-( )	-( )	-( )	-( )	-( )
510 PENALB	4(2)	6(1)	4(1)	5(3)	10(T)	7(1)	6(1)	-( )	-( )	1(3)	1(T)	-( )	-( )	-( )	1(T)
659 PENCAE	2(T)	3(T)	2(T)	2(T)	-( )	-( )	1(T)	7(T)	2(T)	4(T)	3(T)	-( )	5(T)	-( )	6(T)
514 PENWIL	-( )	+(T)	-( )	2(T)	-( )	-( )	-( )	-( )	2(T)	-( )	-( )	2(T)	-( )	-( )	-( )
522 POTGLA	1(3)	2(1)	-( )	1(2)	-( )	2(T)	1(T)	-( )	2(T)	-( )	-( )	-( )	1(T)	-( )	-( )
529 PYRSEC	-( )	-( )	-( )	-( )	-( )	2(T)	3(T)	-( )	-( )	-( )	-( )	-( )	-( )	2(T)	-( )
535 SEDSTE	1(T)	2(T)	2(T)	1(T)	-( )	3(T)	3(T)	-( )	-( )	3(T)	-( )	-( )	5(T)	-( )	1(T)
542 SMIRAC	5(T)	4(T)	7(T)	1(T)	-( )	2(1)	3(T)	2(T)	7(1)	3(T)	5(T)	7(T)	4(T)	4(T)	3(T)
543 SMISTE	-( )	-( )	2(T)	-( )	-( )	-( )	1(T)	-( )	2(T)	1(T)	2(T)	-( )	-( )	4(T)	1(T)
544 SOLMIS	1(T)	1(T)	-( )	-( )	-( )	1(3)	-( )	-( )	-( )	-( )	-( )	-( )	-( )	-( )	-( )
547 THAOCC	5(T)	5(4)	6(T)	2(T)	-( )	4(6)	3(T)	5(T)	-( )	6(2)	6(T)	2(3)	5(1)	10(1)	3(T)
560 TRIOVA	-( )	-( )	2(T)	-( )	-( )	1(3)	-( )	-( )	-( )	-( )	-( )	-( )	-( )	-( )	-( )

****

* CODE TO CONSTANCY VALUES

+ = 0-5%	2 = 15-25%	4 = 35-45%	6 = 55-65%	8 = 75-85%	10 = 95-100%
1 = 5-15%	3 = 25-35%	5 = 45-55%	7 = 65-75%	9 = 85-95%	

(CANOPY COVERAGE EXPRESSEU TO NEAREST %)

APPENDIX A-2.—CONSTANCY* AND AVERAGE CANOPY COVERAGE (PERCENT) OF IMPORTANT PLANTS IN EACH COMMUNITY TYPE OF THE PSME/PHMA, MOIST PHASE

(Abbreviated scientific names of plants are listed below; full names are listed in appendix B.)

STRUCTURAL STAGE	SHRUB-HERB				SAPLING				POLE			MATURE SERAL FOREST	
Community Type	PHMA-CARU	PHMA-AMAL	CEVE-PHMA	CESA-PHMA	PSME/PHMA-CARU	PSME-LAOC/PHMA-CARU	PSME-LAOC/PHMA-AMAL	PSME-LAOC/CEVE-PHMA	PSME/PHMA-CARU	PSME-LAOC/PHMA-CARU	PSME-LAOC/PHMA-AMAL	PSME/PHMA-CARU	PSME-LAOC/PHMA-CARU
Number of Plots	14	11	7	7	4	3	5	6	2	3	6	2	9
TREE SPECIES	********												
1 ABIGRA	1(T)	1(T)	-( )	-( )	-( )	3(T)	-( )	-( )	-( )	-( )	2(T)	-( )	1(T)
6 LAROCC	9(1)	6(1)	7(3)	3(T)	10(5)	10(23)	10(24)	8(3)	10(3)	10(38)	8(29)	10(2)	10(30)
10 PINCON	2(T)	4(T)	4(T)	3(T)	-( )	7(9)	6(2)	5(T)	-( )	-( )	7(32)	5(T)	2(2)
13 PINPON	7(4)	4(2)	7(6)	3(2)	10(10)	10(2)	6(T)	10(34)	5(15)	7(8)	5(5)	10(2)	9(1)
16 PSEMEN	9(3)	9(2)	10(3)	10(1)	10(40)	10(26)	10(29)	10(8)	10(63)	10(47)	10(39)	10(50)	10(26)
SHRUB SPECIES	********												
102 ACEGLA	6(1)	7(14)	7(8)	10(6)	5(T)	7(T)	10(6)	8(3)	5(T)	-( )	8(10)	-( )	6(1)
105 AMEALN	10(6)	9(14)	10(4)	10(7)	10(9)	10(2)	10(10)	10(8)	5(15)	10(2)	10(12)	10(8)	10(3)
198 CEASAN	-( )	-( )	1(T)	10(45)	-( )	-( )	-( )	2(3)	-( )	-( )	-( )	-( )	-( )
107 CEAVEL	4(2)	3(1)	10(35)	9(7)	5(2)	7(2)	2(T)	10(46)	-( )	-( )	-( )	-( )	-( )
111 HOLDIS	1(3)	3(10)	4(5)	7(2)	2(T)	-( )	4(T)	8(10)	-( )	3(15)	-( )	-( )	-( )
115 LONUTA	4(2)	6(T)	3(T)	1(T)	10(1)	-( )	4(T)	5(T)	10(T)	-( )	8(1)	10(T)	7(T)
118 PACMYR	3(1)	3(T)	4(T)	3(T)	-( )	3(T)	-( )	2(T)	5(T)	-( )	2(T)	-( )	-( )
122 PHYMAL	10(31)	10(28)	10(21)	10(21)	10(38)	10(25)	10(20)	10(6)	10(50)	10(23)	10(23)	10(9)	10(38)
130 RIBLAC	1(T)	3(1)	1(T)	-( )	-( )	3(T)	2(T)	-( )	-( )	-( )	-( )	-( )	2(T)
131 RIBVIS	6(3)	4(6)	6(4)	3(T)	7(5)	7(19)	2(T)	2(T)	10(T)	-( )	-( )	-( )	1(T)
132 ROSACI	2(T)	2(T)	1(3)	7(1)	2(T)	7(T)	2(T)	2(T)	5(T)	-( )	-( )	-( )	1(3)
133 ROSGYM	6(T)	4(1)	6(T)	4(1)	7(T)	3(T)	6(1)	7(T)	5(T)	7(2)	8(3)	10(2)	10(3)
136 RUBPAR	6(T)	5(4)	3(8)	4(T)	5(T)	3(T)	4(2)	3(T)	-( )	-( )	2(T)	5(T)	1(T)
137 SALSCO	6(2)	9(7)	6(9)	9(4)	7(5)	10(1)	10(8)	10(9)	-( )	-( )	7(8)	-( )	4(1)
139 SHECAN	1(2)	4(2)	3(T)	1(3)	-( )	-( )	8(4)	7(2)	-( )	-( )	-( )	10(2)	1(T)
142 SPIBET	9(8)	10(6)	10(13)	10(31)	10(15)	10(19)	10(14)	10(13)	10(2)	10(7)	10(2)	10(33)	10(8)
143 SYMALB	9(4)	10(2)	6(1)	10(5)	10(2)	7(33)	8(5)	8(1)	10(2)	10(19)	7(5)	5(T)	10(3)
146 VACGLO	5(3)	5(3)	1(T)	4(T)	7(5)	3(T)	6(6)	5(T)	-( )	3(T)	3(T)	10(8)	6(6)
SUBSHRUB SPECIES	*******												
201 ARCUVA	9(7)	7(9)	6(5)	7(2)	7(5)	7(3)	6(5)	8(14)	-( )	10(T)	3(3)	10(19)	7(4)
203 BERREP	8(2)	5(2)	7(2)	10(3)	10(2)	7(T)	10(4)	10(11)	10(2)	7(2)	8(1)	10(2)	9(1)
204 CLECOL	4(T)	3(T)	1(T)	-( )	5(T)	3(3)	-( )	-( )	10(T)	3(T)	2(T)	5(T)	3(2)
206 LINBOR	3(2)	5(10)	-( )	-( )	-( )	-( )	6(1)	-( )	-( )	3(T)	7(14)	10(2)	6(11)
207 LONCIL	1(T)	-( )	1(T)	-( )	-( )	-( )	-( )	5(6)	-( )	-( )	2(15)	5(T)	1(T)
FERNS AND ALLIES	*******												
271 POLAND	1(3)	-( )	-( )	-( )	2(T)	-( )	-( )	-( )	-( )	-( )	3(8)	-( )	-( )
GRAMINOIDS	************												
301 AGRSPI	-( )	1(T)	-( )	4(2)	-( )	-( )	-( )	-( )	-( )	-( )	-( )	-( )	-( )
303 BROCAR	1(8)	1(T)	-( )	-( )	-( )	3(T)	4(T)	-( )	-( )	-( )	2(T)	-( )	-( )
307 CALRUB	10(33)	10(23)	10(16)	10(28)	10(26)	10(46)	10(15)	10(26)	10(50)	10(54)	10(26)	10(50)	10(40)
308 CARCON	6(T)	5(8)	1(3)	4(1)	2(T)	7(T)	6(T)	5(T)	5(T)	7(T)	2(T)	10(T)	7(T)
309 CARGEY	9(12)	8(6)	7(6)	10(4)	10(10)	10(1)	6(26)	10(3)	10(2)	7(T)	5(1)	10(2)	8(12)
373 DACGLO	1(15)	1(3)	-( )	-( )	-( )	3(T)	-( )	-( )	-( )	-( )	-( )	-( )	-( )
318 FESOCC	4(T)	4(2)	1(T)	4(6)	-( )	3(T)	8(T)	2(T)	5(T)	3(3)	-( )	5(T)	9(T)
334 TRISPI	1(3)	-( )	-( )	-( )	5(T)	-( )	2(T)	-( )	-( )	-( )	-( )	5(T)	2(2)

PERENNIAL FORBS *******

401 ACHMIL	9(T)	8(1)	6(2)	6(1)	7(T)	7(T)	4(T)	8(2)	-( )	7(T)	-( )	-( )	3(T)
404 ALLCER	2(T)	2(T)	1(T)	-( )	-( )	-( )	-( )	-( )	-( )	3(T)	-( )	5(T)	1(T)
405 ANAMAR	4(T)	4(T)	4(T)	9(T)	-( )	3(T)	2(T)	2(T)	-( )	-( )	-( )	-( )	-( )
409 ANTANA	-( )	-( )	3(T)	4(T)	-( )	-( )	-( )	-( )	-( )	-( )	-( )	-( )	-( )
413 ANTRAC	6(3)	5(3)	6(1)	3(T)	10(5)	10(5)	4(2)	2(T)	10(2)	7(T)	2(T)	10(T)	10(3)
415 APOAND	1(3)	-( )	4(6)	6(12)	-( )	3(T)	-( )	7(2)	-( )	-( )	-( )	-( )	-( )
421 ARNCOR	3(T)	4(1)	1(T)	-( )	-( )	-( )	4(T)	3(T)	5(3)	7(9)	5(6)	5(T)	2(2)
422 ARNLAT	4(1)	7(3)	4(T)	3(T)	2(15)	-( )	2(T)	8(T)	5(T)	7(2)	3(19)	5(15)	3(1)
426 ASTCON	8(4)	6(4)	4(2)	6(T)	7(2)	7(T)	10(2)	8(7)	10(8)	7(T)	8(T)	10(T)	9(1)
428 ASTLAE	1(T)	2(T)	-( )	1(T)	2(T)	-( )	-( )	-( )	5(T)	-( )	-( )	-( )	2(T)
429 ASTCAN	2(2)	4(6)	-( )	-( )	-( )	-( )	-( )	-( )	-( )	-( )	-( )	-( )	-( )
430 ASTMIS	1(T)	3(T)	-( )	-( )	-( )	-( )	4(T)	2(T)	-( )	-( )	2(T)	5(3)	2(T)
436 CAMROT	1(T)	1(T)	-( )	7(T)	5(T)	-( )	-( )	7(T)	-( )	3(T)	-( )	-( )	1(T)
438 CASMIN	2(1)	4(5)	1(T)	-( )	2(3)	-( )	2(T)	3(T)	-( )	-( )	-( )	-( )	2(T)
442 CHIUMB	1(T)	2(T)	-( )	-( )	2(T)	-( )	6(T)	-( )	-( )	-( )	8(1)	10(T)	3(T)
455 DISTRA	2(T)	2(T)	-( )	-( )	2(T)	-( )	-( )	-( )	5(T)	-( )	2(T)	5(T)	3(T)
459 EPIANG	9(4)	8(2)	6(T)	9(2)	5(2)	7(19)	6(T)	7(T)	-( )	-( )	-( )	5(T)	3(T)
464 ERYGRA	1(T)	2(T)	3(T)	-( )	-( )	-( )	2(T)	3(T)	10(T)	3(T)	3(T)	5(T)	8(T)
465 FRAVES	8(3)	7(5)	3(T)	1(T)	10(5)	7(T)	10(1)	10(8)	5(T)	10(T)	3(T)	5(T)	10(T)
466 FRAVIR	7(2)	9(2)	6(T)	4(T)	7(2)	3(T)	6(T)	3(T)	10(2)	10(1)	8(T)	10(T)	8(T)
471 GALTRI	1(T)	2(T)	-( )	-( )	-( )	-( )	4(T)	-( )	-( )	-( )	-( )	-( )	-( )
476 GOOOBL	1(T)	-( )	-( )	-( )	2(T)	-( )	6(T)	-( )	5(T)	7(T)	3(T)	5(T)	8(T)
478 HABELE	1(T)	1(T)	1(T)	-( )	-( )	-( )	-( )	2(T)	-( )	-( )	-( )	-( )	-( )
480 HEDOCC	1(T)	2(3)	1(T)	-( )	-( )	-( )	2(3)	2(T)	-( )	-( )	-( )	5(T)	-( )
482 HEUCYL	4(1)	5(1)	1(T)	3(T)	2(T)	3(T)	2(T)	-( )	-( )	3(T)	-( )	-( )	1(T)
483 HIEALB	2(T)	6(T)	6(T)	1(T)	2(T)	3(T)	6(T)	8(T)	-( )	-( )	2(T)	-( )	-( )
484 HIEALF	1(T)	1(T)	-( )	-( )	-( )	3(T)	-( )	-( )	-( )	7(T)	2(T)	10(T)	2(T)
499 LUPINU	2(T)	3(T)	-( )	-( )	5(2)	-( )	4(T)	-( )	5(T)	3(T)	-( )	-( )	3(1)
502 MITSTA	3(2)	2(T)	-( )	-( )	5(T)	-( )	2(T)	-( )	5(T)	3(T)	-( )	-( )	3(T)
510 PENALB	3(1)	5(T)	7(2)	3(T)	5(T)	-( )	4(T)	10(T)	-( )	-( )	-( )	-( )	2(T)
659 PENCAE	1(T)	-( )	-( )	-( )	2(T)	3(T)	2(T)	-( )	-( )	3(T)	-( )	-( )	-( )
514 PENWIL	1(T)	-( )	1(T)	-( )	-( )	-( )	-( )	-( )	-( )	-( )	-( )	5(T)	-( )
526 PYRASA	-( )	2(8)	-( )	-( )	-( )	-( )	-( )	-( )	-( )	-( )	-( )	-( )	-( )
529 PYRSEC	-( )	2(T)	-( )	-( )	-( )	-( )	2(T)	-( )	-( )	-( )	3(T)	-( )	2(T)
535 SEDSTE	1(3)	2(2)	4(T)	-( )	2(T)	-( )	-( )	2(T)	-( )	-( )	-( )	-( )	-( )
542 SMIRAC	6(T)	6(T)	4(T)	3(T)	2(T)	3(T)	10(T)	7(T)	5(T)	-( )	5(1)	10(T)	7(T)
543 SMISTE	3(T)	4(T)	-( )	-( )	-( )	-( )	6(1)	5(T)	-( )	-( )	2(T)	5(T)	-( )
544 SOLMIS	2(T)	1(T)	1(T)	6(1)	-( )	-( )	-( )	-( )	-( )	-( )	-( )	-( )	-( )
547 THAOCC	6(T)	3(T)	1(T)	1(T)	2(15)	-( )	10(1)	2(T)	5(T)	10(1)	3(T)	5(T)	6(1)
550 VALDIO	3(1)	1(T)	-( )	-( )	2(T)	3(T)	-( )	-( )	-( )	-( )	2(T)	-( )	4(T)
558 XERTEN	5(5)	4(5)	4(5)	1(T)	5(8)	3(3)	4(15)	5(2)	5(15)	3(T)	5(T)	5(T)	3(1)

ANNUALS **************

904 EPIPAN	1(2)	3(T)	1(T)	1(15)	-( )	-( )	-( )	-( )	-( )	-( )	-( )	-( )	-( )
906 MELLIN	1(T)	-( )	-( )	1(3)	-( )	-( )	-( )	-( )	-( )	-( )	-( )	-( )	-( )

****
****

* CODE TO CONSTANCY VALUES

+ = 0-5%	2 = 15-25%	4 = 35-45%	6 = 55-65%	8 = 75-85%	10 = 95-100%
1 = 5-15%	3 = 25-35%	5 = 45-55%	7 = 65-75%	9 = 85-95%	

(CANOPY COVERAGE EXPRESSED TO NEAREST %)

APPENDIX A-3.—CONSTANCY* AND AVERAGE CANOPY COVERAGE (PERCENT) OF IMPORTANT PLANTS IN EACH COMMUNITY TYPE OF THE PSME/VAGL, XETE PHASE

(Abbreviated scientific names of plants are listed below; full names are listed in appendix B.)

STRUCTURAL STAGE	SHRUB-HERB				SAPLING				POLE		MATURE	OLD GROWTH
Community Type	VAGL-CARU	XETE-CARU	CARU	CEVE	PICO PSME/ VAGL-CARU	PICO/ XETE-CARU	PICO/ DEPAU-PERATE	PICO-PSMF/ CEVE	PICO-PSME/ VAGL-CARU	PICO-PSME/ VAGL-ARLA	PSME-PICO/ VAGL-CARU	PSME/ VAGL-CARU
Number of Plots	22	7	10	12	18	2	2	11	10	3	9	15
TREE SPECIES ********												
1 ABIGRA	+(T)	-( )	-( )	-( )	-( )	-( )	-( )	-( )	-( )	-( )	-( )	1(3)
2 ABILAS	2(T)	-( )	1(T)	1(T)	2(T)	5(T)	-( )	4(1)	2(T)	7(2)	6(T)	5(3)
6 LAROCC	4(4)	1(T)	-( )	2(T)	3(11)	-( )	5(T)	5(12)	6(12)	-( )	1(T)	5(19)
9 PINALB	-( )	1(T)	-( )	-( )	-( )	5(T)	-( )	1(T)	-( )	3(T)	4(1)	1(T)
10 PINCON	9(6)	4(T)	9(T)	8(8)	9(29)	10(15)	10(85)	10(23)	8(36)	10(50)	10(32)	8(3)
13 PINPON	5(7)	-( )	3(1)	4(2)	4(19)	-( )	-( )	4(10)	6(15)	7(8)	3(5)	4(16)
14 POPTRE	2(1)	1(T)	-( )	2(T)	3(T)	-( )	-( )	3(T)	-( )	-( )	-( )	-( )
16 PSEMEN	10(5)	9(4)	10(1)	10(5)	8(13)	10(19)	5(T)	10(5)	10(28)	10(34)	10(31)	10(40)
SHRUB SPECIES ********												
102 ACEGLA	2(3)	1(T)	2(T)	7(1)	1(T)	-( )	-( )	4(4)	2(T)	7(T)	2(T)	1(T)
104 ALNSIN	3(T)	-( )	1(T)	1(T)	3(T)	-( )	-( )	2(T)	-( )	-( )	-( )	1(T)
105 AMEALN	7(4)	6(15)	6(2)	8(7)	6(7)	5(T)	-( )	5(5)	9(1)	7(2)	7(1)	7(1)
107 CEAVEL	4(2)	4(1)	5(2)	10(40)	3(1)	5(T)	-( )	10(43)	2(8)	-( )	1(T)	2(13)
111 HOLDIS	-( )	-( )	-( )	2(2)	-( )	-( )	-( )	1(3)	-( )	-( )	-( )	-( )
115 LONUTA	6(2)	6(1)	5(2)	3(T)	4(2)	5(T)	-( )	5(T)	2(T)	3(T)	4(T)	5(T)
118 PACMYR	2(T)	-( )	-( )	1(15)	1(T)	-( )	-( )	3(7)	3(10)	-( )	2(3)	1(15)
130 RIBLAC	3(T)	-( )	-( )	-( )	1(T)	-( )	5(T)	-( )	1(T)	3(T)	1(T)	1(T)
131 RIBVIS	8(3)	7(7)	8(3)	5(3)	6(4)	10(2)	-( )	5(3)	2(2)	3(T)	1(T)	3(T)
132 ROSACI	1(T)	-( )	-( )	1(T)	-( )	-( )	-( )	-( )	-( )	-( )	-( )	1(2)
133 ROSGYM	6(T)	3(T)	3(T)	6(T)	4(1)	5(3)	10(T)	2(T)	6(6)	7(T)	6(T)	5(1)
136 RUBPAR	3(T)	3(T)	1(T)	2(1)	1(T)	-( )	-( )	3(5)	1(T)	3(T)	1(T)	-( )
137 SALSCO	8(6)	4(T)	5(4)	8(2)	9(6)	10(T)	5(T)	8(5)	9(6)	10(1)	6(T)	3(T)
139 SHECAN	2(2)	-( )	-( )	2(T)	2(T)	-( )	-( )	2(8)	-( )	7(2)	3(1)	2(T)
140 SORSCO	1(T)	1(T)	-( )	1(T)	-( )	-( )	-( )	-( )	1(T)	3(T)	1(T)	2(T)
142 SPIBET	10(8)	6(2)	9(6)	10(11)	9(9)	10(2)	10(3)	9(6)	8(8)	10(6)	9(3)	9(2)
143 SYMALB	6(2)	1(15)	5(4)	8(2)	3(3)	5(T)	-( )	4(1)	2(T)	3(T)	2(T)	-( )
163 SYMORE	2(4)	3(3)	3(1)	2(2)	-( )	-( )	-( )	3(T)	-( )	-( )	-( )	2(1)
146 VACGLO	10(23)	9(2)	8(1)	10(14)	10(24)	10(3)	10(2)	9(19)	10(32)	10(62)	10(50)	10(40)
148 VACSCO	1(T)	3(T)	2(T)	-( )	3(4)	5(3)	5(3)	1(T)	2(T)	-( )	2(32)	1(3)
SUBSHRUB SPECIES *******												
201 ARCUVA	5(6)	1(38)	4(5)	5(7)	7(17)	-( )	5(T)	7(5)	6(4)	3(T)	4(5)	5(8)
203 BERREP	5(T)	9(3)	9(T)	7(1)	5(2)	-( )	-( )	6(2)	9(3)	10(T)	9(T)	9(T)
206 LINBOR	3(T)	-( )	-( )	-( )	2(T)	-( )	-( )	2(T)	1(T)	-( )	2(T)	1(2)
FERNS AND ALLIES *******												
271 POLAND	+(3)	-( )	-( )	-( )	1(2)	-( )	5(15)	1(15)	-( )	-( )	-( )	-( )
259 PTEAQU	-( )	-( )	-( )	1(T)	-( )	-( )	-( )	-( )	1(15)	-( )	-( )	-( )
GRAMINOIDS ************												
303 BROCAR	+(T)	3(T)	3(2)	1(3)	1(T)	-( )	-( )	1(T)	-( )	-( )	-( )	-( )
307 CALRUB	10(27)	10(33)	10(52)	10(24)	10(34)	10(26)	10(9)	10(28)	10(38)	10(11)	10(17)	10(32)
308 CARCON	5(3)	6(4)	6(T)	2(T)	7(2)	10(T)	5(T)	6(2)	8(1)	10(T)	8(T)	7(T)
309 CARGEY	8(8)	9(21)	10(16)	10(11)	9(7)	10(8)	-( )	8(5)	5(7)	10(5)	9(3)	9(5)
311 CARROS	4(T)	3(T)	3(T)	2(T)	1(T)	5(T)	5(T)	4(T)	-( )	-( )	4(T)	2(T)
316 ELYGLA	-( )	1(T)	-( )	1(3)	-( )	-( )	-( )	-( )	2(T)	-( )	-( )	-( )
318 FESOCC	1(2)	-( )	1(T)	1(T)	-( )	-( )	5(T)	1(3)	-( )	-( )	1(T)	3(1)

PERENNIAL FORBS *******												
401 ACHMIL	6(T)	7(T)	10(T)	6(T)	6(T)	10(T)	5(T)	4(1)	2(T)	3(T)	1(T)	1(T)
404 ALLCER	-( )	-( )	1(T)	-( )	1(T)	-( )	-( )	1(3)	1(T)	-( )	-( )	-( )
405 ANAMAR	3(T)	1(T)	2(T)	1(T)	4(T)	5(T)	-( )	4(1)	-( )	-( )	-( )	-( )
414 ANTMIC	+(T)	-( )	3(T)	-( )	1(T)	5(T)	5(T)	-( )	-( )	-( )	-( )	-( )
413 ANTRAC	6(3)	1(T)	4(T)	4(2)	3(1)	5(T)	-( )	3(T)	4(1)	3(T)	7(2)	7(3)
415 APOAND	+(T)	3(T)	1(T)	1(T)	1(T)	-( )	-( )	-( )	1(T)	3(T)	2(T)	1(T)
419 ARECON	+(T)	-( )	-( )	-( )	-( )	-( )	-( )	-( )	-( )	-( )	-( )	1(8)
578 ARELAT	1(T)	-( )	-( )	1(T)	1(T)	-( )	-( )	-( )	1(T)	-( )	-( )	1(3)
421 ARNCOR	+(T)	3(T)	2(T)	2(T)	1(T)	5(T)	5(T)	2(2)	5(5)	7(2)	3(1)	6(6)
422 ARNLAT	8(3)	4(1)	3(T)	7(3)	9(6)	10(2)	10(32)	6(1)	5(T)	10(34)	6(21)	3(4)
426 ASTCON	4(5)	7(10)	7(9)	5(3)	4(11)	-( )	5(T)	5(1)	1(T)	7(T)	3(T)	5(3)
429 ASTCAN	-( )	1(15)	-( )	-( )	1(8)	-( )	-( )	-( )	-( )	-( )	-( )	-( )
430 ASTMIS	1(T)	-( )	1(T)	-( )	1(3)	-( )	-( )	1(T)	1(T)	3(T)	2(T)	1(2)
438 CASMIN	2(T)	3(T)	2(3)	1(T)	3(2)	-( )	-( )	2(T)	3(T)	-( )	-( )	1(T)
441 CHIMEN	-( )	-( )	-( )	-( )	1(T)	-( )	-( )	-( )	2(T)	3(T)	1(T)	1(T)
442 CHIUMB	3(T)	-( )	-( )	-( )	1(2)	-( )	5(3)	3(T)	9(1)	7(2)	9(3)	7(1)
597 CIRUND	1(T)	-( )	4(T)	-( )	-( )	5(T)	-( )	-( )	-( )	-( )	-( )	-( )
459 EPIANG	8(3)	9(3)	8(T)	7(T)	7(T)	10(T)	5(T)	7(T)	7(T)	7(T)	2(T)	3(T)
464 ERYGRA	2(T)	3(8)	-( )	4(T)	3(T)	5(3)	5(3)	-( )	1(T)	-( )	1(T)	1(T)
465 FRAVES	5(1)	7(2)	5(2)	4(3)	5(6)	-( )	-( )	7(2)	5(T)	7(T)	3(T)	3(2)
466 FRAVIR	3(2)	4(T)	4(2)	3(T)	3(4)	-( )	-( )	3(1)	4(T)	-( )	2(2)	5(T)
474 GEUTRI	-( )	-( )	-( )	-( )	1(2)	-( )	-( )	-( )	-( )	-( )	-( )	-( )
476 GOOOBL	1(T)	-( )	-( )	1(T)	-( )	-( )	-( )	-( )	2(T)	7(T)	8(T)	7(T)
478 HABELE	+(T)	1(T)	-( )	1(T)	-( )	-( )	-( )	-( )	1(T)	-( )	1(T)	1(T)
819 HEDBOR	-( )	1(T)	1(15)	-( )	-( )	-( )	-( )	-( )	1(T)	-( )	-( )	1(T)
480 HEDOCC	1(T)	1(T)	-( )	-( )	1(T)	5(3)	-( )	1(3)	-( )	7(T)	2(T)	1(T)
483 HIEALB	3(T)	7(T)	5(T)	5(T)	4(T)	5(T)	-( )	5(T)	5(1)	3(T)	2(T)	3(T)
484 HIEALF	2(T)	3(T)	4(T)	1(T)	2(T)	-( )	-( )	1(T)	3(T)	7(T)	8(T)	9(T)
499 LUPINU	1(T)	7(1)	3(5)	-( )	3(3)	-( )	-( )	1(T)	1(T)	3(T)	4(2)	3(17)
502 MITSTA	1(8)	-( )	-( )	1(T)	-( )	-( )	5(T)	-( )	-( )	-( )	-( )	-( )
505 OSMCHI	1(1)	-( )	2(T)	-( )	-( )	-( )	-( )	-( )	1(T)	-( )	1(T)	3(T)
507 PEDBRA	1(T)	-( )	-( )	1(T)	1(T)	-( )	-( )	1(T)	1(T)	3(T)	2(T)	4(T)
508 PEDCON	3(3)	-( )	-( )	1(T)	3(1)	-( )	-( )	1(T)	2(T)	-( )	2(T)	3(T)
509 PEDRAC	1(2)	-( )	-( )	-( )	-( )	-( )	-( )	-( )	1(T)	3(T)	3(1)	5(T)
510 PENALB	6(T)	4(T)	7(T)	3(1)	4(T)	-( )	-( )	4(T)	2(T)	-( )	1(T)	1(T)
659 PENCAE	1(2)	1(T)	3(T)	1(T)	1(T)	5(T)	-( )	2(2)	-( )	3(T)	1(T)	3(T)
522 POTGLA	1(1)	1(T)	3(T)	-( )	-( )	-( )	-( )	-( )	-( )	-( )	-( )	-( )
528 PYRPIC	+(T)	-( )	-( )	-( )	-( )	-( )	-( )	1(T)	1(T)	3(T)	4(T)	1(T)
529 PYRSEC	1(T)	-( )	-( )	-( )	1(T)	-( )	5(T)	1(T)	4(T)	7(T)	8(T)	6(T)
535 SEDSTE	-( )	-( )	3(1)	-( )	-( )	-( )	-( )	1(3)	-( )	-( )	1(T)	1(T)
541 SILMEN	-( )	1(T)	1(T)	1(T)	-( )	-( )	-( )	-( )	-( )	-( )	1(T)	2(T)
542 SMIRAC	1(T)	3(T)	1(T)	2(T)	1(T)	-( )	-( )	1(T)	-( )	-( )	-( )	3(T)
547 THAOCC	3(T)	9(T)	3(1)	4(2)	1(T)	5(T)	5(T)	2(2)	1(T)	7(2)	3(1)	4(5)
550 VALDIO	-( )	1(T)	3(T)	2(T)	1(3)	-( )	-( )	-( )	-( )	-( )	1(T)	1(T)
558 XERTEN	10(15)	10(39)	10(2)	10(11)	10(18)	10(26)	10(T)	10(19)	10(21)	10(27)	10(29)	10(38)
ANNUALS **************												
902 COLPAR	+(T)	1(T)	3(T)	2(T)	-( )	-( )	-( )	1(T)	-( )	-( )	-( )	1(T)
904 EPIPAN	1(T)	1(T)	6(T)	2(T)	1(T)	-( )	-( )	-( )	-( )	-( )	-( )	1(T)
906 MELLIN	1(2)	-( )	-( )	-( )	2(5)	-( )	-( )	2(T)	2(2)	7(T)	6(2)	1(2)

****

* CODE TO CONSTANCY VALUES

+ = 0-5%	2 = 15-25%	4 = 35-45%	6 = 55-65%	8 = 75-85%	10 = 95-100%
1 = 5-15%	3 = 25-35%	5 = 45-55%	7 = 65-75%	9 = 85-95%	

(CANOPY COVERAGE EXPRESSED TO NEAREST %)

APPENDIX A-4.—CONSTANCY* AND AVERAGE CANOPY COVERAGE (PERCENT) OF IMPORTANT PLANTS IN EACH COMMUNITY TYPE OF THE ABLA/XETE, VAGL PHASE

(Abbreviated scientific names of plants are listed below; full names are listed in appendix B.)

STRUCTURAL STAGE	SHRUB-HERB						SAPLING			POLE	MATURE	OLD GROWTH
Community Type	PICO/ VAGL- XETE	VAGL- XETE	XETE- CARU	CARU	PICO/ DEPAU PERATE	EPAN	PICO/ VAGL- XETE	PICO/ XETE- CARU	PICO/ CARU	PICO/ VAGL- XETE	PICO- PSME/ VAGL- XETE	ABLA- PSME/ VAGL- XETE
Number of Plots	8	27	12	2	2	6	24	3	1	17	14	9
TREE SPECIES	********											
2 ABILAS	7(6)	8(2)	7(2)	5(T)	10(2)	3(2)	5(5)	3(T)	10(T)	8(3)	10(16)	9(44)
6 LAROCC	1(63)	2(T)	2(T)	-( )	-( )	3(3)	3(9)	10(14)	-( )	5(9)	2(1)	7(6)
7 PICENG	4(6)	3(T)	2(T)	5(T)	10(2)	5(T)	3(3)	-( )	-( )	2(1)	5(7)	7(4)
9 PINALB	-( )	1(T)	2(T)	5(T)	-( )	-( )	1(T)	-( )	10(T)	1(T)	6(3)	6(5)
10 PINCON	9(33)	7(3)	8(3)	5(T)	10(39)	10(3)	9(35)	10(31)	10(38)	10(59)	10(17)	8(5)
16 PSEMEN	6(7)	7(3)	8(1)	10(T)	10(T)	3(T)	8(4)	7(2)	10(T)	9(16)	8(20)	8(29)
SHRUB SPECIES	********											
102 ACEGLA	1(15)	3(3)	-( )	5(T)	5(T)	2(3)	-( )	-( )	-( )	-( )	1(T)	2(8)
104 ALNSIN	2(T)	2(2)	1(T)	-( )	5(T)	2(T)	2(T)	7(T)	-( )	1(T)	1(T)	1(T)
105 AMEALN	4(6)	5(6)	2(2)	10(2)	-( )	2(T)	4(2)	3(T)	-( )	-( )	2(T)	4(1)
107 CEAVEL	-( )	2(T)	2(2)	10(T)	-( )	2(T)	2(2)	7(T)	-( )	-( )	-( )	-( )
115 LONUTA	4(5)	4(2)	4(3)	5(T)	-( )	2(T)	2(2)	-( )	-( )	1(T)	-( )	3(T)
116 MENFER	1(T)	2(T)	-( )	-( )	-( )	-( )	+(T)	-( )	-( )	2(T)	2(T)	2(T)
118 PACMYR	-( )	2(5)	2(8)	-( )	-( )	3(9)	3(5)	3(38)	-( )	2(8)	1(2)	2(9)
130 RIBLAC	4(T)	2(T)	2(1)	5(T)	-( )	2(T)	2(1)	-( )	-( )	1(T)	1(T)	2(T)
131 RIBVIS	2(2)	5(9)	7(2)	10(T)	-( )	5(T)	5(T)	3(3)	-( )	1(T)	1(T)	2(T)
133 ROSGYM	6(1)	3(1)	2(T)	-( )	-( )	2(T)	2(1)	-( )	-( )	1(T)	1(T)	2(T)
136 RUBPAR	2(8)	1(T)	2(T)	5(T)	-( )	2(T)	1(T)	3(T)	-( )	1(T)	-( )	-( )
137 SALSCO	9(10)	7(4)	3(10)	-( )	-( )	7(1)	7(9)	10(3)	10(T)	6(2)	3(T)	-( )
139 SHECAN	-( )	1(1)	-( )	5(T)	-( )	-( )	1(T)	3(T)	-( )	-( )	1(T)	1(3)
140 SORSCO	-( )	1(2)	1(T)	5(T)	-( )	-( )	-( )	-( )	-( )	1(T)	1(T)	2(T)
142 SPIBET	9(15)	7(5)	7(5)	5(15)	-( )	7(1)	8(5)	10(7)	10(T)	8(2)	7(T)	4(1)
163 SYMORE	1(T)	2(4)	-( )	-( )	-( )	-( )	1(2)	-( )	-( )	-( )	-( )	-( )
146 VACGLO	10(24)	10(23)	9(3)	5(3)	10(T)	10(9)	10(32)	10(3)	10(3)	10(40)	10(43)	10(38)
147 VACMYR	-( )	+(3)	-( )	-( )	-( )	-( )	+(T)	-( )	-( )	1(8)	-( )	1(15)
148 VACSCO	7(4)	4(5)	8(2)	-( )	10(T)	3(32)	5(11)	10(5)	10(3)	6(27)	9(23)	3(26)
SUBSHRUB SPECIES	*******											
201 ARCUVA	1(3)	1(T)	2(T)	-( )	-( )	-( )	2(4)	7(9)	10(T)	2(1)	-( )	2(2)
203 BERREP	1(3)	2(T)	4(T)	10(2)	-( )	3(T)	2(T)	-( )	-( )	2(1)	3(T)	4(T)
206 LINBOR	1(T)	1(2)	-( )	-( )	-( )	-( )	+(T)	-( )	-( )	1(T)	-( )	1(T)
FERNS AND ALLIES	*******											
271 POLAND	-( )	+(3)	-( )	-( )	-( )	2(3)	1(2)	3(15)	-( )	1(T)	-( )	-( )
GRAMINOIDS	************											
303 BROCAR	-( )	+(T)	1(T)	10(2)	5(T)	-( )	+(T)	-( )	-( )	1(T)	-( )	1(T)
306 CALPUR	-( )	-( )	1(3)	-( )	-( )	-( )	-( )	-( )	-( )	-( )	1(3)	-( )
307 CALRUB	10(21)	8(14)	10(21)	5(T)	-( )	5(5)	8(11)	10(10)	10(38)	8(7)	6(5)	6(T)
308 CARCON	4(7)	6(3)	7(3)	5(T)	5(T)	8(2)	7(4)	7(3)	10(T)	6(1)	7(T)	6(1)
309 CARGEY	9(7)	9(10)	9(18)	10(26)	10(T)	7(5)	7(4)	10(7)	10(T)	7(T)	9(2)	8(6)
311 CARROS	7(T)	7(2)	7(3)	5(3)	10(9)	8(3)	5(1)	7(T)	10(T)	1(T)	4(T)	2(T)

316 ELYGLA	-( )	+(T)	2(2)	10(T)	-( )	-( )	+(T)	-( )	-( )	-( )	1(T)	1(3)
318 FESOCC	-( )	2(2)	2(T)	5(T)	-( )	-( )	+(T)	3(3)	-( )	1(T)	1(3)	2(T)
325 LUZHIT	-( )	1(T)	-( )	-( )	5(T)	-( )	+(T)	-( )	-( )	1(T)	1(T)	-( )
334 TRISPI	-( )	+(T)	-( )	-( )	5(3)	-( )	+(T)	-( )	-( )	-( )	-( )	-( )
PERENNIAL FORBS *******												
401 ACHMIL	1(T)	4(T)	7(T)	10(T)	5(3)	2(T)	2(1)	7(8)	-( )	-( )	1(T)	-( )
405 ANAMAR	5(1)	4(5)	7(T)	5(3)	10(8)	10(8)	3(3)	10(1)	10(T)	1(T)	-( )	-( )
414 ANTMIC	2(T)	1(T)	2(T)	-( )	5(T)	-( )	1(T)	3(T)	10(T)	-( )	-( )	-( )
413 ANTRAC	2(2)	5(2)	4(3)	10(T)	5(T)	-( )	2(T)	-( )	-( )	2(1)	2(1)	3(T)
421 ARNCOR	2(T)	-( )	1(3)	-( )	-( )	-( )	+(T)	-( )	-( )	-( )	-( )	-( )
422 ARNLAT	9(5)	10(5)	7(1)	5(T)	10(T)	5(13)	8(5)	7(8)	10(T)	8(12)	9(6)	9(12)
426 ASTCON	2(3)	2(4)	3(8)	5(T)	-( )	3(8)	1(7)	-( )	-( )	2(T)	1(T)	1(3)
427 ASTFOL	-( )	-( )	1(15)	5(3)	-( )	-( )	-( )	-( )	-( )	-( )	-( )	1(3)
429 ASTCAN	-( )	-( )	-( )	-( )	-( )	-( )	+(3)	-( )	-( )	-( )	-( )	-( )
430 ASTMIS	1(T)	+(T)	-( )	-( )	-( )	-( )	1(2)	-( )	-( )	1(T)	1(T)	1(T)
438 CASMIN	-( )	+(T)	-( )	5(T)	-( )	-( )	1(5)	-( )	-( )	-( )	1(T)	1(T)
441 CHIMEN	-( )	-( )	1(T)	-( )	-( )	-( )	-( )	-( )	-( )	1(T)	1(T)	3(T)
442 CHIUMB	1(T)	1(T)	2(T)	-( )	-( )	3(T)	3(3)	3(T)	-( )	8(4)	9(T)	10(1)
597 CIRUND	1(T)	-( )	-( )	-( )	-( )	2(15)	-( )	7(2)	-( )	-( )	-( )	-( )
447 CLIUNI	-( )	+(T)	-( )	-( )	-( )	2(T)	-( )	-( )	-( )	-( )	-( )	1(3)
459 EPIANG	9(3)	8(1)	9(4)	10(T)	5(T)	10(35)	7(2)	10(1)	10(T)	3(T)	3(T)	1(T)
464 ERYGRA	1(T)	2(T)	-( )	-( )	-( )	-( )	+(T)	-( )	-( )	1(T)	1(T)	-( )
465 FRAVES	1(3)	3(2)	3(1)	-( )	-( )	2(15)	2(2)	3(3)	-( )	1(T)	-( )	1(T)
466 FRAVIR	1(T)	3(T)	4(1)	10(3)	-( )	-( )	1(T)	-( )	-( )	1(T)	1(T)	-( )
476 GOOOBL	-( )	-( )	-( )	-( )	-( )	-( )	1(T)	-( )	-( )	4(T)	5(T)	8(T)
480 HEDOCC	-( )	+(T)	1(T)	-( )	-( )	2(T)	3(8)	7(9)	-( )	-( )	2(5)	-( )
630 HEDSUL	-( )	+(T)	-( )	5(3)	-( )	-( )	-( )	3(T)	-( )	1(T)	1(T)	-( )
483 HIEALB	7(T)	3(T)	2(T)	5(T)	5(T)	3(T)	4(T)	7(2)	-( )	4(T)	1(T)	-( )
484 HIEALF	-( )	3(T)	5(T)	5(T)	10(T)	3(T)	2(T)	-( )	10(T)	4(T)	8(T)	6(T)
833 ILLRIV	-( )	-( )	-( )	5(3)	-( )	-( )	-( )	-( )	-( )	-( )	-( )	-( )
499 LUPINU	2(T)	5(T)	5(T)	5(T)	10(8)	-( )	2(2)	-( )	-( )	3(T)	4(T)	2(8)
502 MITSTA	-( )	1(2)	1(T)	-( )	-( )	2(T)	+(T)	-( )	-( )	1(T)	-( )	1(T)
505 OSMCHI	-( )	1(T)	-( )	-( )	-( )	-( )	+(T)	-( )	-( )	1(T)	1(T)	1(T)
506 OSMOCC	-( )	-( )	1(T)	5(T)	-( )	-( )	+(T)	-( )	-( )	-( )	1(T)	1(T)
507 PEDBRA	-( )	1(2)	-( )	-( )	-( )	-( )	1(T)	-( )	-( )	4(T)	4(T)	2(T)
508 PEDCON	-( )	1(T)	1(T)	-( )	-( )	-( )	2(T)	-( )	10(T)	1(T)	3(1)	-( )
509 PEDRAC	-( )	1(T)	1(T)	-( )	-( )	-( )	1(T)	-( )	10(T)	4(T)	4(3)	3(T)
510 PENALB	1(T)	3(T)	2(T)	5(T)	-( )	2(T)	2(T)	10(T)	-( )	-( )	-( )	-( )
513 PENPRO	-( )	+(T)	1(3)	-( )	-( )	-( )	+(T)	-( )	10(T)	1(T)	-( )	-( )
529 PYRSEC	-( )	1(T)	-( )	-( )	-( )	-( )	2(T)	-( )	-( )	4(T)	4(T)	9(T)
531 PYRVIR	-( )	-( )	-( )	-( )	-( )	-( )	+(T)	-( )	-( )	1(T)	1(T)	1(T)
542 SMIRAC	1(T)	1(T)	1(T)	-( )	-( )	-( )	+(T)	-( )	-( )	1(T)	-( )	1(T)
547 THAOCC	1(T)	4(1)	3(5)	5(T)	-( )	-( )	1(2)	-( )	-( )	1(T)	3(1)	4(8)
551 VALSIT	-( )	2(T)	3(1)	5(T)	-( )	-( )	-( )	-( )	-( )	-( )	1(T)	2(T)
557 VIOORB	1(T)	1(T)	-( )	-( )	-( )	2(T)	1(T)	-( )	-( )	3(T)	4(T)	2(T)
558 XERTEN	10(29)	10(28)	10(32)	10(3)	5(T)	10(9)	10(29)	10(30)	10(T)	10(35)	10(52)	10(45)
ANNUALS **************												
904 EPIPAN	1(T)	1(T)	3(T)	10(T)	-( )	2(T)	+(T)	-( )	-( )	-( )	-( )	-( )
906 MELLIN	-( )	-( )	-( )	-( )	-( )	2(T)	1(T)	3(3)	-( )	1(T)	1(T)	-( )

* CODE TO CONSTANCY VALUES

+ = 0-5%	2 = 15-25%	4 = 35-45%	6 = 55-65%	8 = 75-85%	10 = 95-100%
1 = 5-15%	3 = 25-35%	5 = 45-55%	7 = 65-75%	9 = 85-95%	

(CANOPY COVERAGE EXPRESSED TO NEAREST %)

APPENDIX A-5.—CONSTANCY* AND AVERAGE CANOPY COVERAGE (PERCENT) OF IMPORTANT PLANTS IN EACH COMMUNITY TYPE OF THE ABLA/XETE, VASC PHASE

(Abbreviated scientific names of plants are listed below; full names are listed in appendix B.)

STRUCTURAL STAGE	SHRUB-HERB				SAPLING				POLE	MATURE		OLD GROWTH
Community Type	PICO/ VASC-XETE	VASC-XETE	XETE-CARU	PICO/ EPAN-VASC	PICO/ VASC-XETE	PICO/ XETE-CARU	PICO/ CARU	PICO/ DEPAU-PERATE	PICO/ VASC-XETE	PICO-ABLA/ VASC-XETE	PICO/ VASC-XETE	ABLA/ DEPAU-PERATE
Number of Plots	6	11	3	2	34	3	2	1	6	3	5	1
TREE SPECIES	********											
2 ABILAS	7(4)	8(6)	-( )	10(8)	7(5)	10(5)	5(T)	-( )	7(4)	10(23)	8(T)	10(63)
6 LAROCC	2(T)	1(T)	3(T)	-( )	-( )	-( )	-( )	-( )	2(T)	-( )	-( )	-( )
7 PICENG	2(T)	2(2)	-( )	-( )	4(1)	3(T)	5(T)	-( )	2(3)	3(15)	2(T)	10(3)
9 PINALB	3(T)	4(1)	-( )	-( )	5(T)	3(T)	5(T)	-( )	2(T)	10(5)	6(T)	10(3)
10 PINCON	10(27)	10(8)	10(2)	10(26)	10(43)	7(15)	10(15)	10(85)	10(70)	10(15)	10(43)	10(3)
13 PINPON	-( )	1(T)	-( )	-( )	-( )	3(38)	-( )	-( )	-( )	-( )	-( )	-( )
16 PSEMEN	2(T)	2(T)	-( )	-( )	4(3)	3(T)	5(T)	-( )	5(T)	3(15)	8(T)	10(3)
SHRUB SPECIES	********											
115 LONUTA	2(T)	1(T)	-( )	-( )	2(3)	-( )	10(T)	-( )	2(3)	-( )	2(T)	-( )
133 ROSGYM	2(15)	1(T)	-( )	-( )	+(T)	-( )	-( )	-( )	-( )	-( )	-( )	-( )
137 SALSCO	2(3)	5(T)	3(T)	-( )	6(T)	3(T)	10(T)	10(T)	-( )	-( )	4(2)	-( )
142 SPIBET	10(6)	6(3)	3(T)	10(T)	9(3)	7(2)	5(3)	10(15)	5(1)	10(T)	8(T)	-( )
146 VACGLO	10(14)	9(11)	7(T)	10(15)	8(5)	7(T)	-( )	10(3)	10(14)	7(2)	10(1)	-( )
148 VACSCO	10(30)	10(36)	10(3)	10(15)	10(48)	10(3)	10(2)	10(3)	10(46)	10(70)	10(48)	-( )
SUBSHRUB SPECIES *******												
201 ARCUVA	3(T)	-( )	3(3)	-( )	2(2)	7(2)	5(T)	-( )	-( )	-( )	4(T)	-( )
203 BERREP	-( )	1(T)	-( )	-( )	+(T)	3(T)	5(T)	-( )	-( )	-( )	2(T)	-( )
GRAMINOIDS *************												
303 BROCAR	-( )	1(T)	-( )	-( )	1(5)	3(T)	5(T)	-( )	2(T)	-( )	-( )	-( )
307 CALRUB	8(29)	8(10)	10(5)	10(8)	8(14)	10(15)	10(20)	10(3)	5(2)	-( )	8(2)	-( )
308 CARCON	8(2)	5(5)	10(5)	10(9)	6(1)	7(2)	5(3)	-( )	3(8)	7(T)	8(T)	-( )
309 CARGEY	7(T)	7(8)	10(30)	10(15)	6(8)	7(15)	5(15)	10(T)	5(T)	7(T)	6(2)	-( )
311 CARROS	8(7)	7(8)	10(10)	10(9)	9(3)	10(6)	10(8)	10(T)	3(T)	3(T)	4(T)	-( )
318 FESOCC	-( )	1(T)	-( )	-( )	-( )	-( )	-( )	-( )	2(15)	-( )	2(T)	-( )
334 TRISPI	-( )	1(T)	-( )	-( )	2(T)	3(T)	5(3)	-( )	-( )	-( )	-( )	-( )
PERENNIAL FORBS	*******											
401 ACHMIL	2(T)	1(T)	3(T)	-( )	2(T)	3(T)	-( )	10(T)	2(T)	-( )	-( )	-( )
405 ANAMAR	7(2)	5(2)	3(T)	10(2)	3(T)	7(T)	-( )	-( )	2(T)	-( )	-( )	-( )
414 ANTMIC	2(T)	1(T)	-( )	-( )	+(T)	7(T)	-( )	-( )	2(T)	-( )	-( )	-( )
413 ANTRAC	-( )	-( )	3(T)	-( )	2(T)	-( )	-( )	-( )	3(T)	-( )	2(T)	-( )
422 ARNLAT	7(1)	9(1)	7(T)	10(2)	8(7)	10(1)	10(T)	-( )	10(6)	7(T)	6(7)	10(T)
426 ASTCON	2(T)	3(10)	-( )	-( )	1(1)	-( )	-( )	-( )	-( )	-( )	-( )	-( )
430 ASTMIS	-( )	-( )	-( )	-( )	1(T)	-( )	5(T)	-( )	2(T)	3(T)	2(T)	-( )
442 CHIUMB	-( )	1(T)	3(T)	-( )	3(T)	-( )	-( )	-( )	7(1)	3(T)	10(3)	10(T)
608 EPIALP	-( )	-( )	3(T)	5(T)	+(T)	3(T)	5(T)	-( )	-( )	-( )	-( )	-( )
459 EPIANG	7(1)	8(7)	7(9)	10(26)	7(T)	7(T)	10(T)	10(T)	2(15)	-( )	-( )	-( )
465 FRAVES	-( )	2(3)	-( )	-( )	1(T)	-( )	5(T)	-( )	-( )	-( )	-( )	-( )
476 GOOOBL	-( )	-( )	-( )	-( )	1(T)	-( )	-( )	-( )	-( )	3(T)	6(T)	10(T)

480 HEDOCC	2(T)	-( )	3(T)	-( )	3(10)	7(15)	5(T)	-( )	2(15)	3(3)	2(T)	-( )
483 HIEALB	10(T)	5(2)	7(T)	10(2)	3(T)	3(T)	5(T)	-( )	2(T)	-( )	-( )	-( )
484 HIEALF	-( )	1(T)	3(T)	-( )	1(T)	-( )	5(T)	-( )	2(T)	7(T)	6(T)	10(T)
499 LUPINU	7(T)	5(T)	3(3)	5(T)	3(1)	3(T)	5(T)	-( )	5(T)	-( )	2(T)	-( )
509 PEDRAC	-( )	-( )	-( )	-( )	1(T)	-( )	-( )	-( )	2(T)	3(T)	6(T)	-( )
510 PENALB	2(T)	-( )	3(T)	-( )	1(T)	7(T)	5(T)	-( )	-( )	-( )	-( )	-( )
526 PYRASA	-( )	-( )	-( )	-( )	1(T)	-( )	-( )	-( )	-( )	-( )	-( )	10(T)
528 PYRPIC	-( )	1(T)	-( )	-( )	1(T)	-( )	-( )	-( )	-( )	-( )	2(T)	-( )
529 PYRSEC	-( )	-( )	-( )	-( )	1(T)	-( )	-( )	-( )	2(T)	3(T)	2(T)	10(T)
531 PYRVIR	-( )	-( )	-( )	-( )	-( )	-( )	-( )	-( )	-( )	-( )	2(T)	10(T)
557 VIOORB	-( )	2(8)	3(T)	-( )	+(T)	-( )	-( )	-( )	3(2)	-( )	2(T)	10(T)
558 XERTEN	10(27)	8(29)	10(23)	10(38)	10(24)	10(23)	10(2)	10(3)	10(28)	10(26)	10(26)	10(T)
ANNUALS **************												
906 MELLIN	2(T)	-( )	3(T)	-( )	1(3)	-( )	5(T)	-( )	-( )	-( )	2(T)	-( )

****
****

* CODE TO CONSTANCY VALUES

+ = 0-5%   2 = 15-25%   4 = 35-45%   6 = 55-65%   8 = 75-85%   10 = 95-100%
1 = 5-15%   3 = 25-35%   5 = 45-55%   7 = 65-75%   9 = 85-95%

(CANOPY COVERAGE EXPRESSED TO NEAREST %)

APPENDIX A-6.—CONSTANCY* AND AVERAGE CANOPY COVERAGE (PERCENT) OF IMPORTANT PLANTS IN EACH COMMUNITY TYPE OF THE ABLA/MEFE, WARM PHASE

(Abbreviated scientific names of plants are listed below; full names are listed in appendix B.)

STRUCTURAL STAGE	SHRUB-HERB							SAPLING						POLE		MATURE	OLD GROWTH
Community Type	MEFE-VAGL	EPAN-MEFE	VAGL	EPAN	SASC	RIVI	ARLA	ABLA/MEFE-VAGL	ABLA-(OTHERS)/MEFE-EPAN	5SPP/VAGL	5SPP/EPAN	5SPP/SASC	ABLA-(OTHERS)/MEFE-VAGL	5SPP/MEFE-VAGL	5SPP/MEFE-VAGL	ABLA-(OTHERS)/MEFE-VAGL
Number of Plots	15	11	15	12	2	3	5	11	4	13	2	4	1	7	13	6
TREE SPECIES	********															
2 ABILAS	10(6)	9(8)	9(2)	10(1)	10(T)	7(2)	8(T)	10(24)	10(8)	9(6)	10(2)	10(T)	10(38)	10(15)	10(12)	10(28)
6 LAROCC	3(T)	5(T)	5(1)	3(1)	10(T)	-( )	6(1)	5(26)	10(12)	7(18)	10(15)	5(38)	10(15)	6(11)	6(15)	8(13)
7 PICENG	6(1)	9(2)	7(T)	10(1)	5(T)	10(1)	6(T)	7(7)	10(4)	8(2)	10(T)	10(8)	-( )	7(27)	10(13)	10(12)
9 PINALB	-( )	2(T)	2(T)	1(T)	-( )	-( )	-( )	-( )	-( )	2(1)	-( )	-( )	-( )	-( )	-( )	2(T)
10 PINCON	5(2)	7(3)	9(5)	8(6)	10(2)	7(2)	6(1)	7(3)	7(18)	8(16)	10(15)	10(15)	10(15)	9(32)	10(15)	5(2)
13 PINPON	1(T)	1(T)	3(4)	2(1)	-( )	3(15)	-( )	3(23)	-( )	1(T)	-( )	-( )	-( )	-( )	-( )	-( )
14 POPTRE	3(T)	2(T)	3(1)	2(T)	-( )	10(1)	4(2)	1(T)	7(T)	2(5)	5(T)	2(3)	-( )	-( )	-( )	-( )
15 POPTRI	2(1)	4(T)	3(1)	5(T)	5(T)	7(T)	6(T)	1(T)	5(T)	3(T)	-( )	-( )	-( )	-( )	-( )	-( )
16 PSEMEN	9(1)	8(4)	8(4)	7(T)	5(T)	10(1)	6(T)	10(6)	7(10)	8(4)	10(9)	10(5)	10(T)	10(20)	8(14)	7(5)
SHRUB SPECIES	********															
102 ACEGLA	2(T)	1(T)	2(1)	-( )	-( )	-( )	-( )	5(4)	2(3)	2(T)	-( )	5(T)	10(T)	-( )	2(2)	-( )
104 ALNSIN	7(7)	5(5)	8(7)	8(3)	10(T)	7(T)	8(2)	6(9)	7(6)	8(9)	10(15)	7(6)	10(T)	9(4)	9(2)	7(4)
105 AMEALN	3(1)	5(T)	6(3)	-( )	-( )	3(T)	2(T)	7(3)	2(T)	2(T)	-( )	2(T)	10(3)	1(T)	2(T)	-( )
107 CEAVEL	1(2)	2(T)	2(T)	1(T)	-( )	7(T)	2(T)	1(T)	-( )	1(T)	-( )	-( )	-( )	-( )	-( )	-( )
115 LONUTA	7(3)	7(T)	6(4)	3(2)	5(3)	3(T)	6(1)	5(5)	7(5)	5(4)	-( )	2(15)	10(3)	3(2)	8(3)	2(T)
116 MENFER	10(37)	10(17)	10(2)	7(2)	10(2)	10(1)	10(2)	10(21)	10(21)	9(2)	10(2)	10(1)	10(15)	10(21)	10(24)	10(36)
118 PACMYR	1(3)	3(7)	3(3)	3(1)	10(2)	-( )	-( )	2(9)	5(15)	1(T)	10(9)	2(15)	10(15)	4(15)	-( )	3(T)
130 RIBLAC	7(1)	7(3)	7(1)	6(4)	-( )	7(8)	8(1)	5(3)	10(4)	6(T)	10(T)	5(2)	-( )	3(2)	5(T)	3(T)
131 RIBVIS	4(1)	5(6)	6(9)	3(1)	5(T)	10(31)	4(2)	6(3)	5(T)	8(4)	10(2)	7(13)	-( )	3(T)	2(T)	2(T)
133 ROSGYM	3(1)	-( )	3(T)	-( )	5(T)	-( )	4(T)	5(1)	-( )	2(T)	5(T)	-( )	10(T)	3(2)	3(T)	-( )
135 RUBIDA	-( )	1(T)	1(T)	2(T)	-( )	7(2)	2(3)	-( )	-( )	2(T)	-( )	2(T)	-( )	-( )	-( )	-( )
136 RUBPAR	7(2)	8(3)	8(2)	5(2)	5(T)	10(6)	8(2)	9(2)	7(T)	9(5)	10(9)	10(2)	10(3)	6(T)	8(5)	7(1)
137 SALSCO	6(8)	8(9)	9(9)	7(3)	10(38)	10(3)	10(1)	7(10)	10(1)	8(8)	10(2)	10(33)	10(T)	9(3)	5(T)	-( )
138 SAMRAC	2(5)	5(2)	5(3)	7(T)	-( )	10(5)	8(1)	2(T)	5(T)	5(T)	5(T)	5(T)	-( )	-( )	2(T)	2(T)
139 SHECAN	1(T)	-( )	1(T)	-( )	5(T)	-( )	-( )	1(3)	-( )	1(T)	-( )	-( )	-( )	-( )	-( )	-( )
140 SORSCO	2(T)	-( )	1(T)	1(T)	-( )	-( )	-( )	1(T)	-( )	2(T)	-( )	-( )	-( )	-( )	-( )	-( )
142 SPIBET	6(3)	6(4)	9(4)	3(1)	5(3)	3(T)	2(3)	7(5)	5(T)	8(3)	10(T)	5(2)	10(15)	3(2)	3(T)	2(T)
144 TAXBRE	-( )	-( )	1(T)	-( )	-( )	-( )	-( )	-( )	-( )	-( )	-( )	2(T)	-( )	1(T)	1(T)	2(3)
146 VACGLO	10(21)	9(11)	10(20)	9(3)	10(2)	7(2)	8(1)	10(25)	10(18)	10(36)	10(3)	10(2)	10(15)	10(17)	9(37)	8(19)
148 VACSCO	3(4)	4(8)	3(13)	2(8)	5(3)	-( )	2(3)	1(.3)	7(10)	3(10)	-( )	-( )	10(15)	3(19)	2(T)	3(T)
SUBSHRUB SPECIES	*******															
201 ARCUVA	1(T)	-( )	-( )	1(T)	-( )	-( )	2(3)	1(T)	2(T)	-( )	5(T)	-( )	-( )	-( )	-( )	-( )
206 LINBOR	4(14)	3(1)	6(9)	1(T)	5(3)	-( )	2(T)	5(17)	7(21)	2(13)	-( )	2(T)	10(3)	-( )	4(10)	2(3)
FERNS AND ALLIES	*******															
271 POLAND	1(T)	1(3)	1(2)	-( )	-( )	-( )	-( )	1(3)	-( )	2(2)	5(3)	-( )	-( )	-( )	-( )	-( )
GRAMINOIDS	*************															
303 BROCAR	1(T)	-( )	1(T)	2(T)	5(T)	-( )	2(T)	1(T)	-( )	2(T)	-( )	-( )	-( )	-( )	-( )	-( )
304 BROVUL	1(T)	3(T)	1(T)	2(1)	-( )	-( )	2(T)	-( )	2(T)	2(3)	-( )	-( )	-( )	3(T)	3(T)	2(T)
307 CALRUB	7(12)	5(3)	8(11)	4(1)	5(38)	10(2)	10(T)	9(12)	2(T)	5(7)	-( )	5(9)	-( )	6(5)	1(T)	-( )
308 CARCON	4(4)	3(1)	4(1)	7(1)	5(T)	7(8)	4(T)	5(2)	7(1)	5(4)	10(8)	2(3)	10(T)	-( )	3(T)	2(T)
309 CARGEY	5(5)	5(4)	8(3)	4(1)	5(T)	7(8)	4(T)	7(8)	5(T)	5(T)	10(T)	2(15)	10(T)	4(2)	2(T)	2(T)
311 CARROS	7(1)	7(T)	7(T)	7(4)	-( )	7(T)	8(T)	7(T)	5(T)	8(2)	5(T)	5(2)	-( )	-( )	2(T)	2(T)

316 ELYGLA	-( )	-( )	-( )	1(T)	-( )	-( )	-( )	-( )	-( )	2(3)	-( )	2(T)	-( )	-( )	-( )	-( )
318 FESOCC	1(T)	-( )	4(T)	3(T)	-( )	3(3)	6(1)	-( )	2(T)	3(T)	-( )	2(T)	-( )	1(T)	1(T)	2(T)
326 LUZPAR	2(T)	2(8)	2(T)	3(T)	-( )	7(2)	8(1)	-( )	-( )	-( )	-( )	2(T)	-( )	-( )	-( )	2(T)
PERENNIAL FORBS *******																
401 ACHMIL	1(T)	3(1)	4(T)	4(T)	5(T)	10(T)	6(T)	1(T)	7(T)	3(T)	5(T)	5(T)	-( )	-( )	-( )	-( )
405 ANAMAR	1(T)	8(1)	8(2)	7(6)	10(3)	7(2)	6(1)	4(1)	7(5)	8(1)	10(9)	7(T)	-( )	1(15)	-( )	-( )
413 ANTRAC	2(2)	3(T)	4(T)	2(T)	5(T)	7(T)	2(T)	3(1)	-( )	2(T)	5(T)	5(T)	-( )	1(T)	1(T)	-( )
578 ARELAT	1(T)	1(15)	3(17)	1(15)	-( )	7(20)	4(20)	1(T)	-( )	-( )	-( )	-( )	-( )	1(15)	2(19)	-( )
422 ARNLAT	7(4)	9(10)	7(5)	9(12)	10(8)	7(9)	10(38)	8(13)	7(10)	9(8)	10(19)	10(23)	-( )	7(38)	5(22)	8(19)
426 ASTCON	2(T)	1(T)	1(T)	2(T)	5(T)	3(T)	2(T)	1(T)	-( )	2(T)	-( )	10(1)	-( )	1(T)	2(T)	-( )
442 CHIUMB	7(T)	4(T)	4(T)	2(T)	-( )	-( )	-( )	4(T)	7(T)	5(T)	5(T)	2(T)	10(T)	9(1)	9(1)	8(2)
447 CLIUNI	1(T)	3(T)	1(2)	-( )	-( )	-( )	-( )	3(T)	2(T)	2(2)	-( )	-( )	-( )	3(T)	1(15)	3(2)
449 COPOCC	1(T)	1(T)	1(T)	-( )	-( )	-( )	-( )	1(T)	-( )	-( )	-( )	-( )	-( )	-( )	2(2)	-( )
608 EPIALP	-( )	3(T)	1(T)	3(T)	-( )	3(T)	4(T)	1(T)	-( )	-( )	-( )	-( )	-( )	-( )	-( )	-( )
459 EPIANG	9(1)	10(21)	9(12)	10(40)	10(15)	10(6)	8(6)	6(2)	10(15)	10(8)	10(39)	10(8)	10(T)	1(T)	2(T)	-( )
465 FRAVES	2(1)	1(T)	3(T)	1(T)	5(3)	7(9)	-( )	3(6)	-( )	4(1)	-( )	5(T)	-( )	-( )	2(T)	-( )
466 FRAVIR	1(T)	1(T)	3(T)	1(T)	-( )	3(3)	2(T)	2(T)	-( )	2(T)	-( )	5(T)	-( )	1(T)	-( )	-( )
471 GALTRI	1(T)	2(T)	1(T)	5(T)	-( )	3(T)	4(T)	-( )	-( )	2(T)	5(T)	5(T)	-( )	1(T)	2(T)	2(T)
476 GOOOBL	5(T)	2(T)	1(T)	1(T)	-( )	-( )	-( )	3(T)	-( )	1(T)	-( )	-( )	-( )	9(T)	10(T)	8(1)
480 HEDOCC	-( )	-( )	1(15)	-( )	-( )	-( )	-( )	1(3)	-( )	-( )	5(T)	-( )	-( )	-( )	-( )	-( )
483 HIEALB	2(T)	3(T)	3(T)	1(T)	-( )	-( )	-( )	1(T)	2(T)	6(T)	10(T)	5(T)	-( )	1(T)	-( )	-( )
484 HIEALF	3(T)	2(T)	4(T)	7(T)	-( )	7(T)	6(T)	-( )	2(T)	2(T)	-( )	2(T)	-( )	3(T)	2(T)	3(T)
499 LUPINU	1(T)	-( )	1(T)	-( )	-( )	3(T)	-( )	2(T)	-( )	2(T)	-( )	-( )	-( )	1(T)	-( )	-( )
502 MITSTA	2(6)	3(T)	3(T)	2(T)	-( )	-( )	2(T)	2(T)	2(T)	3(1)	10(T)	2(T)	-( )	1(3)	1(T)	-( )
505 OSMCHI	-( )	-( )	1(T)	2(T)	-( )	-( )	2(T)	-( )	2(T)	-( )	-( )	-( )	-( )	1(T)	2(T)	3(2)
507 PEDBRA	1(T)	-( )	-( )	-( )	-( )	-( )	-( )	2(2)	-( )	2(T)	5(T)	-( )	-( )	-( )	1(T)	-( )
509 PEDRAC	1(T)	3(T)	2(T)	2(T)	-( )	-( )	-( )	3(T)	2(T)	2(T)	-( )	-( )	-( )	9(T)	3(T)	3(T)
510 PENALB	1(T)	1(T)	3(T)	1(T)	5(T)	3(T)	-( )	4(T)	2(T)	3(T)	10(T)	5(T)	-( )	-( )	-( )	-( )
519 POLPUL	-( )	-( )	-( )	1(3)	-( )	-( )	4(2)	-( )	-( )	2(T)	-( )	-( )	-( )	-( )	1(T)	-( )
526 PYRASA	3(T)	5(T)	3(T)	2(T)	-( )	-( )	-( )	5(T)	2(T)	2(T)	-( )	5(T)	-( )	3(T)	7(T)	8(1)
529 PYRSEC	5(T)	8(T)	3(T)	4(T)	-( )	-( )	4(T)	4(T)	10(T)	5(T)	5(T)	5(T)	10(T)	4(1)	10(T)	10(T)
531 PYRVIR	-( )	-( )	-( )	-( )	-( )	-( )	-( )	-( )	2(T)	1(T)	-( )	-( )	-( )	3(T)	2(T)	2(T)
870 SENFOE	1(T)	2(T)	1(T)	2(T)	-( )	-( )	2(T)	-( )	-( )	2(T)	-( )	-( )	-( )	-( )	-( )	-( )
539 SENTRI	-( )	1(T)	1(T)	3(T)	-( )	3(T)	6(T)	1(T)	2(T)	1(T)	-( )	-( )	-( )	3(T)	1(T)	2(T)
541 SILMEN	-( )	-( )	1(T)	-( )	-( )	3(T)	2(T)	-( )	-( )	-( )	-( )	-( )	-( )	1(T)	2(T)	2(3)
542 SMIRAC	1(T)	-( )	1(T)	-( )	-( )	-( )	-( )	1(15)	-( )	-( )	-( )	-( )	-( )	-( )	-( )	2(T)
543 SMISTE	1(T)	-( )	-( )	-( )	-( )	-( )	-( )	1(T)	-( )	2(T)	-( )	-( )	-( )	1(T)	2(T)	-( )
544 SOLMIS	-( )	1(T)	-( )	-( )	5(T)	-( )	-( )	-( )	-( )	2(2)	-( )	-( )	-( )	-( )	-( )	-( )
547 THAOCC	5(T)	4(1)	4(T)	6(T)	-( )	10(T)	6(1)	5(T)	5(2)	5(1)	5(T)	10(T)	-( )	7(1)	8(2)	2(3)
560 TRIOVA	1(T)	1(T)	1(T)	-( )	-( )	-( )	2(T)	1(T)	-( )	-( )	-( )	-( )	-( )	1(T)	2(T)	2(T)
551 VALSIT	-( )	-( )	-( )	1(T)	-( )	-( )	-( )	1(3)	-( )	-( )	-( )	-( )	-( )	-( )	-( )	-( )
552 VERVIR	-( )	1(T)	-( )	2(T)	-( )	3(T)	2(T)	-( )	-( )	1(T)	-( )	-( )	-( )	1(T)	1(T)	-( )
557 VIOORB	2(T)	5(T)	3(2)	2(T)	5(T)	3(T)	4(T)	3(T)	7(T)	2(T)	5(T)	5(T)	-( )	10(T)	6(T)	7(1)
558 XERTEN	10(10)	9(3)	8(9)	9(5)	-( )	3(T)	8(2)	9(9)	7(5)	9(9)	10(2)	2(3)	10(3)	10(15)	9(15)	7(23)

* CODE TO CONSTANCY VALUES

+ = 0-5%	2 = 15-25%	4 = 35-45%	6 = 55-65%	8 = 75-85%	10 = 95-100%
1 = 5-15%	3 = 25-35%	5 = 45-55%	7 = 65-75%	9 = 85-95%	

(CANOPY COVERAGE EXPRESSED TO NEAREST %)

APPENDIX A-7.—CONSTANCY* AND AVERAGE CANOPY COVERAGE (PERCENT) OF IMPORTANT PLANTS IN EACH COMMUNITY TYPE OF THE ABLA/MEFE, COLD PHASE

(Abbreviated scientific names of plants are listed below; full names are listed in appendix B.)

STRUCTURAL STAGE	SHRUB-HERB					SAPLING				POLE	MATURE	OLD GROWTH
Community Type	MEFE VACC	EPAN MEFE	EPAN	WET MEADOW	MEFE WET MEADOW	ABLA-(PIEN)/ MEFE-VACC	PICO-(PIEN-ABLA)/ MEFE VACC	PICO-(PIEN-ABLA)/ MEFE-EPAN	PICO-(PIEN-ABLA)/ WET MEADOW	PICO-(PIEN-ABLA)/ MFFE-VACC	PICO-PIEN-ABLA/ MEFE-VACC	ABLA PIEN/ MEFE-VACC
Number of Plots	15	5	12	9	3	5	5	2	5	4	7	7
TREE SPECIES ********												
2 ABILAS	9(8)	10(4)	10(T)	10(1)	10(6)	10(20)	10(16)	10(15)	10(7)	10(8)	10(15)	10(23)
6 LAROCC	-( )	4(T)	1(T)	-( )	-( )	-( )	6(5)	-( )	2(T)	-( )	-( )	3(T)
7 PICENG	9(3)	8(2)	7(4)	9(1)	10(1)	10(12)	8(5)	10(9)	10(2)	7(2)	9(18)	10(28)
9 PINALB	3(2)	-( )	3(T)	8(T)	3(T)	4(T)	6(1)	5(T)	2(3)	7(1)	4(1)	9(T)
10 PINCON	8(6)	10(11)	10(3)	4(1)	3(T)	6(6)	10(20)	5(3)	10(7)	10(68)	10(10)	7(2)
12 PINMON	-( )	-( )	-( )	-( )	-( )	-( )	-( )	-( )	-( )	2(T)	1(3)	-( )
15 POPTRI	-( )	2(T)	3(1)	-( )	-( )	-( )	-( )	-( )	2(T)	-( )	-( )	-( )
16 PSEMEN	3(T)	4(2)	2(T)	-( )	-( )	4(2)	4(T)	5(T)	2(T)	5(T)	1(3)	3(2)
19 TSUMER	1(T)	-( )	1(T)	-( )	-( )	-( )	-( )	-( )	-( )	-( )	-( )	3(T)
SHRUB SPECIES ********												
104 ALNSIN	5(5)	6(5)	4(3)	2(2)	-( )	2(T)	2(T)	10(2)	4(T)	5(T)	-( )	-( )
115 LONUTA	3(1)	-( )	-( )	4(1)	7(2)	6(6)	2(T)	-( )	8(1)	2(T)	3(T)	1(T)
116 MENFER	10(37)	10(20)	10(2)	10(5)	10(70)	10(58)	10(25)	10(26)	10(10)	10(26)	10(48)	10(67)
118 PACMYR	-( )	2(15)	-( )	1(3)	-( )	-( )	2(T)	5(3)	-( )	2(T)	-( )	-( )
130 RIBLAC	3(1)	8(1)	6(T)	8(3)	7(9)	6(2)	-( )	10(T)	6(1)	-( )	-( )	-( )
131 RIBVIS	2(2)	4(T)	-( )	1(T)	3(T)	-( )	-( )	5(T)	2(T)	2(T)	-( )	-( )
136 RUBPAR	3(3)	4(T)	2(T)	2(8)	7(2)	2(T)	-( )	5(T)	-( )	2(T)	-( )	-( )
137 SALSCO	4(8)	6(1)	7(T)	4(T)	-( )	4(T)	8(5)	5(T)	10(T)	5(2)	-( )	-( )
138 SAMRAC	4(T)	4(T)	4(1)	9(4)	7(T)	2(T)	2(T)	5(3)	8(T)	-( )	1(T)	-( )
140 SORSCO	1(2)	2(T)	-( )	1(T)	-( )	-( )	-( )	-( )	2(T)	2(T)	-( )	-( )
142 SPIBET	3(4)	8(1)	1(T)	-( )	3(T)	-( )	2(T)	-( )	-( )	-( )	1(T)	-( )
146 VACGLO	10(18)	10(20)	10(5)	9(2)	10(7)	8(8)	8(10)	10(9)	10(10)	10(23)	10(20)	9(20)
147 VACMYR	-( )	-( )	-( )	-( )	-( )	-( )	2(15)	-( )	2(38)	-( )	-( )	1(38)
148 VACSCO	9(27)	10(7)	8(6)	10(8)	10(5)	10(31)	8(38)	5(38)	6(2)	10(41)	10(31)	7(24)
SUBSHRUB SPECIES *******												
206 LINBOR	-( )	-( )	-( )	-( )	-( )	2(T)	2(T)	-( )	-( )	2(15)	-( )	-( )
FERNS AND ALLIES *******												
271 POLAND	2(1)	2(3)	1(15)	2(2)	-( )	4(2)	-( )	5(T)	-( )	5(T)	-( )	-( )
GRAMINOIDS ************												
302 AGRSPP	-( )	-( )	-( )	1(T)	-( )	-( )	-( )	-( )	6(T)	-( )	-( )	-( )
303 BROCAR	1(T)	2(T)	1(T)	1(T)	7(T)	-( )	-( )	-( )	2(T)	-( )	-( )	-( )
305 CALCAN	1(T)	-( )	-( )	3(T)	-( )	-( )	2(T)	-( )	4(T)	-( )	-( )	-( )
306 CALPUR	-( )	-( )	1(3)	3(1)	3(3)	-( )	-( )	-( )	-( )	-( )	1(T)	-( )
307 CALRUB	3(7)	2(15)	2(1)	1(15)	3(T)	4(8)	2(T)	-( )	-( )	5(9)	-( )	-( )
308 CARCON	3(T)	6(1)	3(4)	6(4)	-( )	2(T)	6(T)	5(T)	2(T)	2(T)	-( )	-( )
309 CARGEY	5(1)	10(2)	7(5)	9(10)	-( )	4(9)	2(T)	5(T)	6(14)	2(T)	3(T)	-( )
275 CARILL	-( )	-( )	2(T)	6(10)	-( )	-( )	-( )	-( )	-( )	-( )	-( )	-( )
311 CARROS	7(2)	10(5)	10(10)	10(6)	10(5)	8(5)	10(T)	5(15)	10(3)	-( )	-( )	-( )

313 CINLAT	-( )	-( )	-( )	-( )	3(T)	-( )	-( )	-( )	2(3)	-( )	-( )	-( )
314 DESATR	-( )	-( )	-( )	1(3)	3(T)	-( )	-( )	-( )	2(T)	-( )	1(T)	-( )
316 ELYGLA	-( )	-( )	2(T)	1(T)	-( )	-( )	-( )	-( )	4(8)	-( )	-( )	-( )
318 FESOCC	-( )	2(3)	2(3)	1(3)	-( )	-( )	-( )	-( )	2(T)	-( )	-( )	-( )
325 LUZHIT	2(1)	2(T)	2(T)	7(6)	3(T)	-( )	-( )	-( )	6(1)	-( )	3(T)	1(T)
326 LUZPAR	-( )	4(3)	2(1)	4(1)	3(3)	2(T)	-( )	10(T)	6(5)	-( )	-( )	-( )
279 POACAN	1(T)	-( )	-( )	1(T)	3(T)	-( )	-( )	-( )	6(T)	-( )	-( )	-( )
334 TRISPI	-( )	2(T)	2(2)	1(T)	-( )	-( )	-( )	-( )	4(T)	-( )	-( )	-( )
PERENNIAL FORBS	*******											
401 ACHMIL	-( )	-( )	2(T)	-( )	-( )	-( )	2(T)	-( )	4(T)	-( )	-( )	-( )
405 ANAMAR	3(1)	8(5)	10(7)	8(3)	3(T)	4(T)	8(T)	10(9)	8(2)	-( )	-( )	-( )
951 ANGDAW	-( )	-( )	-( )	4(5)	-( )	-( )	-( )	-( )	-( )	-( )	-( )	-( )
414 ANTMIC	1(T)	-( )	2(T)	-( )	-( )	-( )	-( )	-( )	4(2)	-( )	-( )	-( )
420 AREMAC	-( )	-( )	1(3)	1(T)	-( )	-( )	-( )	-( )	-( )	-( )	-( )	-( )
422 ARNLAT	5(3)	6(15)	7(5)	9(9)	10(6)	10(6)	8(1)	10(26)	10(14)	10(9)	4(10)	6(5)
442 CHIUMB	5(T)	4(T)	-( )	-( )	-( )	2(T)	2(3)	10(T)	-( )	10(2)	1(T)	4(T)
597 CIRUND	-( )	-( )	2(T)	2(2)	-( )	-( )	-( )	-( )	-( )	-( )	-( )	-( )
447 CLIUNI	-( )	-( )	-( )	3(T)	7(T)	-( )	-( )	5(T)	-( )	-( )	1(T)	-( )
458 DODJEF	-( )	-( )	-( )	4(2)	-( )	-( )	-( )	-( )	-( )	-( )	-( )	-( )
608 EPIALP	3(T)	8(T)	7(T)	4(2)	7(T)	-( )	-( )	5(T)	6(T)	-( )	-( )	-( )
459 EPIANG	7(T)	10(15)	10(32)	9(16)	10(1)	8(T)	10(1)	10(26)	10(4)	-( )	-( )	-( )
471 GALTRI	-( )	-( )	-( )	-( )	-( )	-( )	-( )	-( )	2(3)	-( )	-( )	-( )
476 GOOOBL	3(T)	-( )	-( )	-( )	-( )	2(T)	2(T)	5(T)	-( )	5(T)	9(T)	6(T)
483 HIEALB	3(1)	2(3)	2(2)	1(T)	-( )	4(T)	4(T)	5(T)	-( )	2(T)	-( )	-( )
484 HIEALF	1(T)	4(T)	3(T)	1(T)	-( )	-( )	4(T)	-( )	4(T)	-( )	1(T)	-( )
489 LIGCAN	-( )	-( )	-( )	4(1)	7(T)	-( )	-( )	-( )	2(T)	-( )	-( )	1(T)
499 LUPINU	1(T)	4(T)	1(T)	6(3)	-( )	4(2)	-( )	-( )	2(T)	-( )	1(T)	-( )
649 MITPEN	-( )	-( )	-( )	-( )	3(3)	-( )	-( )	-( )	-( )	-( )	-( )	-( )
502 MITSTA	-( )	2(3)	-( )	-( )	3(T)	-( )	-( )	5(T)	4(2)	-( )	1(T)	-( )
505 OSMCHI	-( )	-( )	-( )	-( )	3(T)	-( )	-( )	-( )	2(3)	-( )	-( )	-( )
509 PEDRAC	1(T)	2(T)	-( )	-( )	-( )	4(T)	4(T)	-( )	2(T)	2(T)	1(T)	1(T)
510 PENALB	-( )	4(T)	1(T)	1(3)	-( )	-( )	2(T)	-( )	-( )	-( )	-( )	-( )
519 POLPUL	1(T)	-( )	-( )	1(T)	7(8)	-( )	-( )	-( )	6(2)	-( )	-( )	-( )
526 PYRASA	4(T)	2(T)	-( )	-( )	-( )	6(T)	4(T)	5(T)	-( )	10(T)	4(T)	3(T)
529 PYRSEC	3(T)	2(T)	2(T)	-( )	3(T)	2(T)	2(T)	-( )	-( )	10(T)	6(1)	10(T)
539 SENTRI	1(T)	4(T)	2(T)	10(9)	10(3)	2(T)	-( )	5(T)	10(5)	-( )	3(T)	1(T)
544 SOLMIS	-( )	-( )	-( )	-( )	-( )	-( )	2(T)	-( )	6(T)	-( )	-( )	-( )
547 THAOCC	1(T)	-( )	1(T)	6(7)	3(T)	2(T)	-( )	-( )	4(2)	2(T)	1(T)	1(T)
548 TIATRI	-( )	4(T)	-( )	2(T)	7(T)	2(3)	-( )	5(T)	2(T)	-( )	1(T)	1(T)
560 TRIOVA	-( )	-( )	1(T)	2(T)	3(T)	-( )	-( )	-( )	-( )	2(T)	1(T)	-( )
690 TROLAX	-( )	-( )	-( )	8(T)	-( )	-( )	-( )	-( )	2(T)	-( )	-( )	-( )
551 VALSIT	-( )	2(T)	-( )	4(2)	3(T)	-( )	-( )	-( )	2(15)	-( )	-( )	-( )
552 VERVIR	-( )	2(3)	-( )	8(2)	7(T)	-( )	-( )	-( )	4(3)	-( )	1(T)	1(T)
557 VIOORB	1(T)	4(T)	2(T)	3(T)	7(T)	2(T)	4(T)	5(T)	6(T)	7(T)	4(T)	4(T)
558 XERTEN	10(21)	8(18)	9(5)	9(10)	10(6)	10(10)	10(12)	10(3)	10(4)	7(31)	10(21)	10(26)

****
****

* CODE TO CONSTANCY VALUES

+ = 0-5%	2 = 15-25%	4 = 35-45%	6 = 55-65%	8 = 75-85%	10 = 95-100%
1 = 5-15%	3 = 25-35%	5 = 45-55%	7 = 65-75%	9 = 85-95%	

(CANOPY COVERAGE EXPRESSED TO NEAREST %)

APPENDIX B.—SCIENTIFIC NAMES OF SPECIES CODED IN APPENDIX A

TREE SPECIES	GENUS	SPECIES
ABIGRA	ABIES	GRANDIS
ABILAS	ABIES	LASIOCARPA
LAROCC	LARIX	OCCIDENTALIS
PICENG	PICEA	ENGELMANNII
PINALB	PINUS	ALBICAULIS
PINCON	PINUS	CONTORTA
PINMON	PINUS	MONTICOLA
PINPON	PINUS	PONDEROSA
POPTRE	POPULUS	TREMULOIDES
POPTRI	POPULUS	TRICHOCARPA
PSEMEN	PSEUDOTSUGA	MENZIESII
TSUMER	TSUGA	MERTENSIANA

SHRUB SPECIES		
ACEGLA	ACER	GLABRUM
ALNSIN	ALNUS	SINUATA
AMEALN	AMELANCHIER	ALNIFOLIA
CEASAN	CEANOTHUS	SANGUINEUS
CEAVEL	CEANOTHUS	VELUTINUS
HOLDIS	HOLODISCUS	DISCOLOR
LONUTA	LONICERA	UTAHENSIS
MENFER	MENZIESIA	FERRUGINEA
PACMYR	PACHISTIMA	MYRSINITES
PHILEW	PHILADELPHUS	LEWISII
PHYMAL	PHYSOCARPUS	MALVACEUS
PRUEMA	PRUNUS	EMARGINATA
PRUVIR	PRUNUS	VIRGINIANA
PURTRI	PURSHIA	TRIDENTATA
RIBCER	RIBES	CEREUM
RIBLAC	RIBES	LACUSTRE
RIBVIS	RIBES	VISCOSISSIMUM
ROSACI	ROSA	ACICULARIS
ROSGYM	ROSA	GYMNOCARPA
ROSWOO	ROSA	WOODSII
RUBIDA	RUBUS	IDAEUS
RUBPAR	RUBUS	PARVIFLORUS
SALSCO	SALIX	SCOULERIANA
SAMCER	SAMBUCUS	CERULEA
SAMRAC	SAMBUCUS	RACEMOSA
SHECAN	SHEPHERDIA	CANADENSIS
SORSCO	SORBUS	SCOPULINA
SPIBET	SPIRAEA	BETULIFOLIA
SYMALB	SYMPHORICARPOS	ALBUS
SYMORE	SYMPHORICARPOS	OREOPHILUS
TAXBRE	TAXUS	BREVIFOLIA

PERENNIAL FORBS		
ACHMIL	ACHILLEA	MILLEFOLIUM
ALLCER	ALLIUM	CERNUUM
ANAMAR	ANAPHALIS	MARGARITACEAE
ANGDAW	ANGELICA	DAWSONII
ANTANA	ANTENNARIA	ANAPHALOIDES
ANTMIC	ANTENNARIA	MICROPHYLLA
ANTRAC	ANTENNARIA	RACEMOSA
APOAND	APOCYNUM	ANDROSAEMIFOLIUM
ARECON	ARENARIA	CONGESTA
ARELAT	ARENARIA	LATERIFLORA
AREMAC	ARENARIA	MACROPHYLLA
ARNCOR	ARNICA	CORDIFOLIA
ARNLAT	ARNICA	LATIFOLIA
ASTCON	ASTER	CONSPICUUS
ASTFOL	ASTER	FOLIACEUS
ASTLAE	ASTER	LAEVIS
ASTCAN	ASTRAGALUS	CANADENSIS
ASTMIS	ASTRAGALUS	MISER
BALSAG	BALSAMORHIZA	SAGITTATA
CAMROT	CAMPANULA	ROTUNDIFOLIA
CASMIN	CASTILLEJA	MINIATA
CHIMEN	CHIMAPHILA	MENZIESII
CHIUMB	CHIMAPHILA	UMBELLATA
CIRUND	CIRSIUM	UNDULATUM
CLIUNI	CLINTONIA	UNIFLORA
COPOCC	COPTIS	OCCIDENTALIS
DISTRA	DISPORUM	TRACHYCARPUM
DODJEF	DODECATHEON	JEFFREYI
EPIALP	EPILOBIUM	ALPINUM
EPIANG	EPILOBIUM	ANGUSTIFOLIUM
ERYGRA	ERYTHRONIUM	GRANDIFLORUM
FRAVES	FRAGARIA	VESCA
FRAVIR	FRAGARIA	VIRGINIANA
GALTRI	GALIUM	TRIFLORUM
GEUTRI	GEUM	TRIFLORUM
GOOOBL	GOODYERA	OBLONGIFOLIA
HABELE	HABENARIA	ELEGANS
HEDBOR	HEDYSARUM	BOREALIS
HEDOCC	HEDYSARUM	OCCIDENTALIS
HEDSUL	HEDYSARUM	SULPHURESCENS
HEUCYL	HEUCHERA	CYLINDRICA
HIEALB	HIERACIUM	ALBERTINUM & CYNOGLO
HIEALF	HIERACIUM	ALBIFLORUM
ILLRIV	ILLIAMNA	RIVULARIS
LIGCAN	LIGUSTICUM	CANBYI
LITRUD	LITHOSPERMUM	RUDERALE

APPENDIX B (con.)

VACGLO	VACCINIUM	GLOBULARE
VACMYR	VACCINIUM	MYRTILLUS
VACSCO	VACCINIUM	SCOPARIUM

SUBSHRUB SPECIES

ARCUVA	ARTOSTAPHYLOS	UVA-URSI
BERREP	BERBERIS	REPENS
CLECOL	CLEMATIS	COLUMBIANA
LINBOR	LINNAEA	BOREALIS
LONCIL	LONICERA	CILIOSA

FERNS AND ALLIES

POLAND	POLYSTICUM	ANDERSONII
PTEAQU	PTERIDIUM	AQUILINUM

GRAMINOIDS

AGRSPI	AGROPYRON	SPICATUM
AGRSPP	AGROSTIS	SPP.
BROCAR	BROMUS	CARINATUS
BROVUL	BROMUS	VULGARIS
CALCAN	CALAMAGROSTIS	CANADENSIS
CALPUR	CALAMAGROSTIS	PURPURASCENS
CALRUB	CALAMAGROSTIS	RUBESCENS
CARCON	CAREX	CONCINNOIDES
CARGEY	CAREX	GEYERI
CARILL	CAREX	ILLOTA
CARROS	CAREX	ROSSII
CINLAT	CINNA	LATIFOLIA
DACGLO	DACTYLIS	GLOMERATA
DESATR	DESCHAMPSIA	ATROPURPUREA
ELYGLA	ELYMUS	GLAUCUS
FESIDA	FESTUCA	IDAHOENSIS
FESOCC	FESTUCA	OCCIDENTALIS
FESSCA	FESTUCA	SCABRELLA
LUZHIT	LUZULA	HITCHCOCKII
LUZPAR	LUZULA	PARVIFLORA
POACAN	POA	CANBYI
POACOM	POA	COMPRESSA
POANFR	POA	NERVOSA
TRISPI	TRISETUM	SPICATUM

LUPINU	LUPINUS	SPP
MITPEN	MITELLA	PENTANDRA
MITSTA	MITELLA	STAUROPETALA
OSMCHI	OSMORHIZA	CHILENSIS
OSMOCC	OSMORHIZA	OCCIDENTALIS
PEDBRA	PEDICULARIS	BRACTEOSA
PEDCON	PEDICULARIS	CONTORTA
PEDRAC	PEDICULARIS	RACEMOSA
PENALB	PENSTEMON	ALBERTINUS
PENCAE	PENSTEMON	CAELESTINUS
PENPRO	PENSTEMON	PROCERUS
PENWIL	PENSTEMON	WILCOXII
POLPUL	POLEMONIUM	PULCHERRIMUM
POTGLA	POTENTILLA	GLANDULOSA
PYRASA	PYROLA	ASARIFOLIA
PYRPIC	PYROLA	PICTA
PYRSEC	PYROLA	SECUNDA
PYRVIR	PYROLA	VIRENS
SEDSTE	SEDUM	STENOPETALUM
SENFOE	SENECIO	FOETIDUS
SENTRI	SENECIO	TRIANGULARIS
SILMEN	SILENE	MENZIESII
SMIRAC	SMILACINA	RACEMOSA
SMISTE	SMILACINA	STELLATA
SOLMIS	SOLIDAGO	MISSOURIENSIS
THAOCC	THALICTRUM	OCCIDENTALE
TIATRI	TIARELLA	TRIFOLIATA
TRIOVA	TRILLIUM	OVATUM
TROLAX	TROLLIUS	LAXUS
VALDIO	VALERIANA	DIOICA & OCCIDENTALI
VALSIT	VALERIANA	SITCHENSIS
VERVIR	VERATRUM	VIRIDE
VIOORB	VIOLA	ORBICULATA
XERTEN	XEROPHYLLUM	TENAX

ANNUALS

COLPAR	COLLINSIA	PARVIFLORA
EPIPAN	EPILOBIUM	PANICULATUM
MELLIN	MELAMPYRUM	LINEARE

APPENDIX C.—FIFTY-YEAR SITE INDEXES BY SPECIES FOR EACH HABITAT TYPE PHASE, COMPARED WITH SIMILARLY DERIVED VALUES FROM PFISTER AND OTHERS (1977) FOR WESTERN MONTANA[1]

Data from the current study

Habitat type and phase		Site indexes and maximum heights (in feet)				
		Pinus ponderosa	Pseudotsuga menziesii	Larix occidentalis	Pinus contorta	Picea[2] engelmannii
PSME/PHMA	Dry Phase	52 ± 9 93 ± 5	46 ± 3 84 ± 6			
	Moist Phase		52 ± ?	60 ± 6 104 ± 17		
PSME/VAGL h.t. (includes some ABLA/XETE sites having poorly represented Abies lasiocarpa)		55 ± ? 100 ± ?	56 ± 11 88 ± 8	100 ± 17	51 ± 6	
ABLA/XETE	VAGL Phase		81 ± 12	100 ± ?	48 ± 4 81 ± 17	
	VASC Phase				35 ± ? 69 ± 8	
ABLA/MEFE	Warm Phase		105 ± ?	109 ± 15	53 ± 4 95 ± ?	75 ± ? 124 ± 15
	Cold Phase				45 ± 5 85 ± ?	105 ± 10

Data from Pfister and others 1977, for western Montana

Habitat type	Site indexes and maximum heights (in feet)				
	Pinus ponderosa	Pseudotsuga menziesii	Larix occidentalis	Pinus contorta	Picea[2] englemannii
entire PSME/PHMA h.t.	59 ± 14 118 ± 20	58 ± 6 101 ± ?	57 ± ?	48 ± ?	
PSME/VAGL h.t.	115 ± 15	44 ± 4 85 ± 11			
entire ABLA/XETE h.t.		40 ± 6 86 ± 8	51 ± ? 96 ± 10	46 ± 6 82 ± ?	56 ± ?
entire ABLA/MEFE h.t.		50 ± 8 95 ± ?	67 ± ? 106 ± 17	56 ± 6 88 ± 8	60 ± 10 109 ± 7

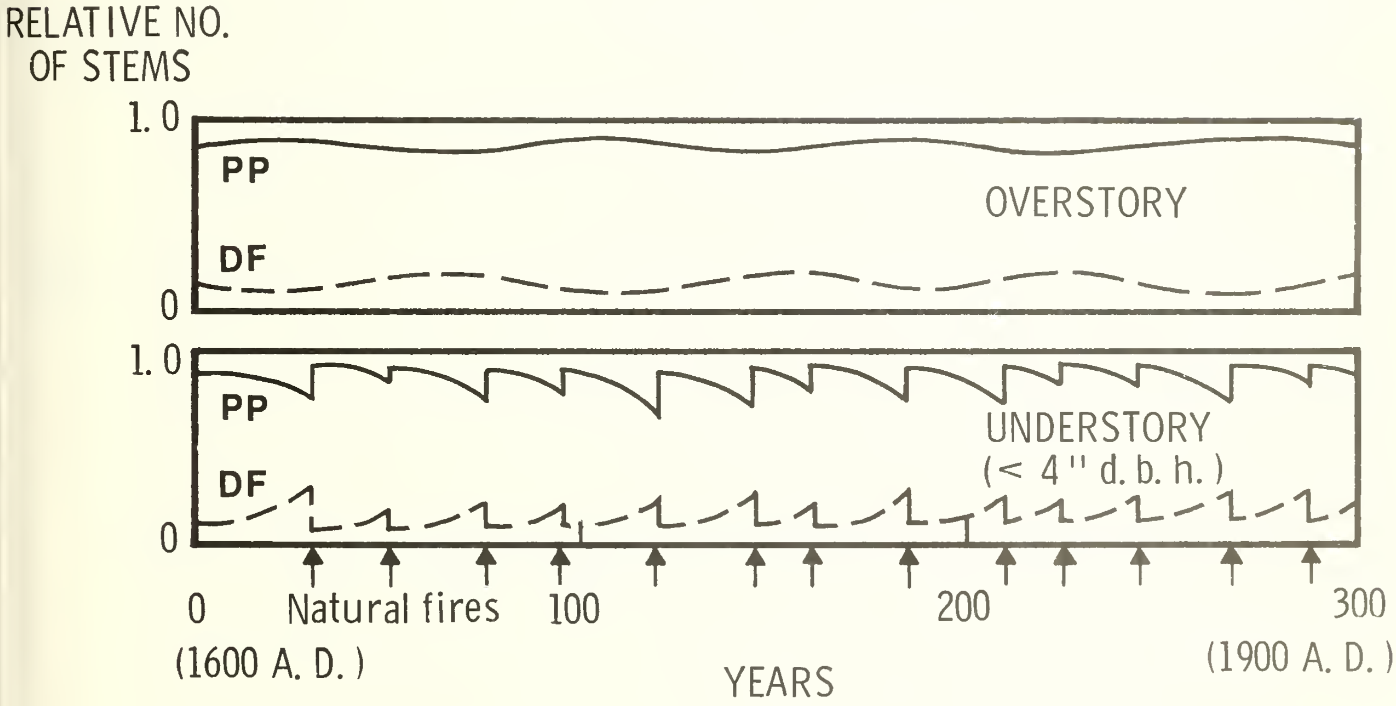
[1]Maximum heights of dominant old-growth trees are underlined. Means are shown where n = 3 or more; confidence limits for estimating the mean are given where n = 5 or more.

[2]Picea site indexes are based on breast-high age while other species have indexes based on total age.

APPENDIX D-1.—HYPOTHESIZED TREE SUCCESSION ON THE PSME/PHMA, DRY PHASE

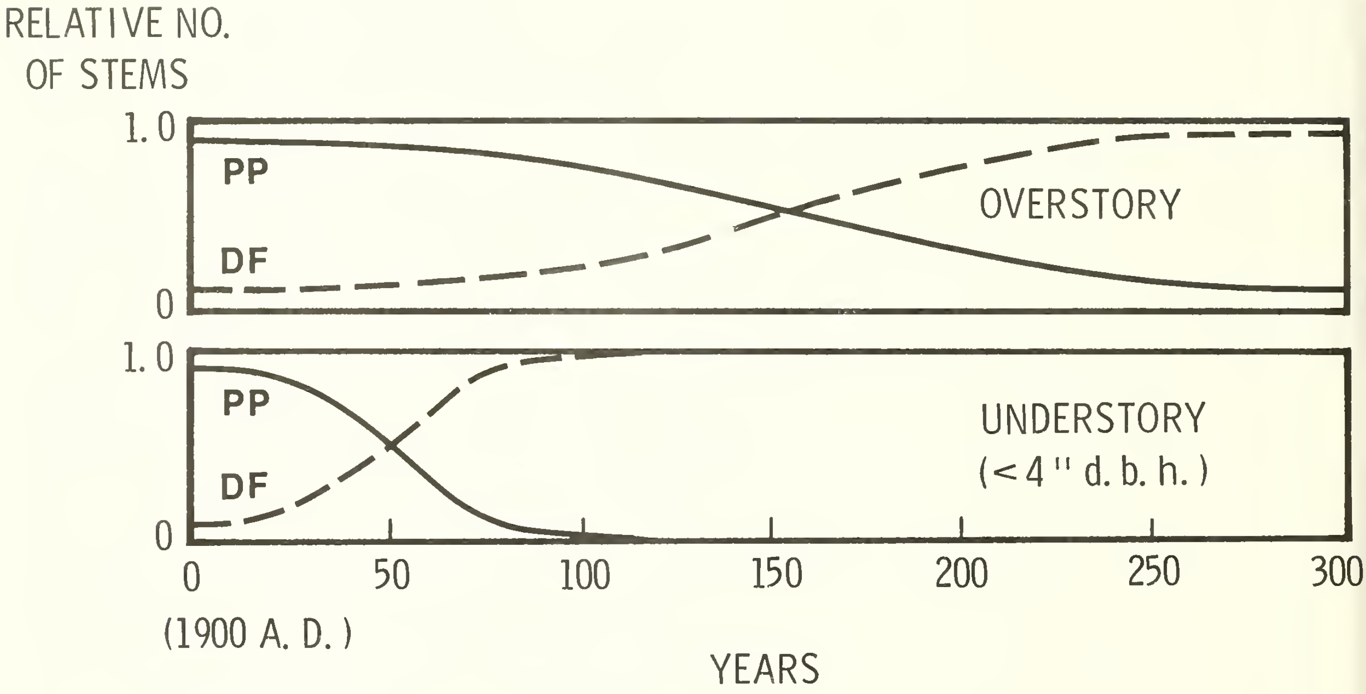
Case 1.—Natural Succession With Understory Fires

This figure shows a common pattern of tree succession in a pre-1900 stand in the dry phase. Low- to medium-intensity surface fires generally at 5- to 30-year intervals continually favored ponderosa pine (PP) by killing a higher proportion of the Douglas-fir (DF) regeneration (Arno 1976; Gruell and others 1982). Ponderosa pine saplings have thicker bark, thicker twigs and buds, and less foliage near the ground; thus, they are less vulnerable to light fires than Douglas-firs of comparable age. This fire regime maintained ponderosa pine as the major overstory component, resulting in parklike stands of large ponderosa pine (many age classes) with a relatively open understory.



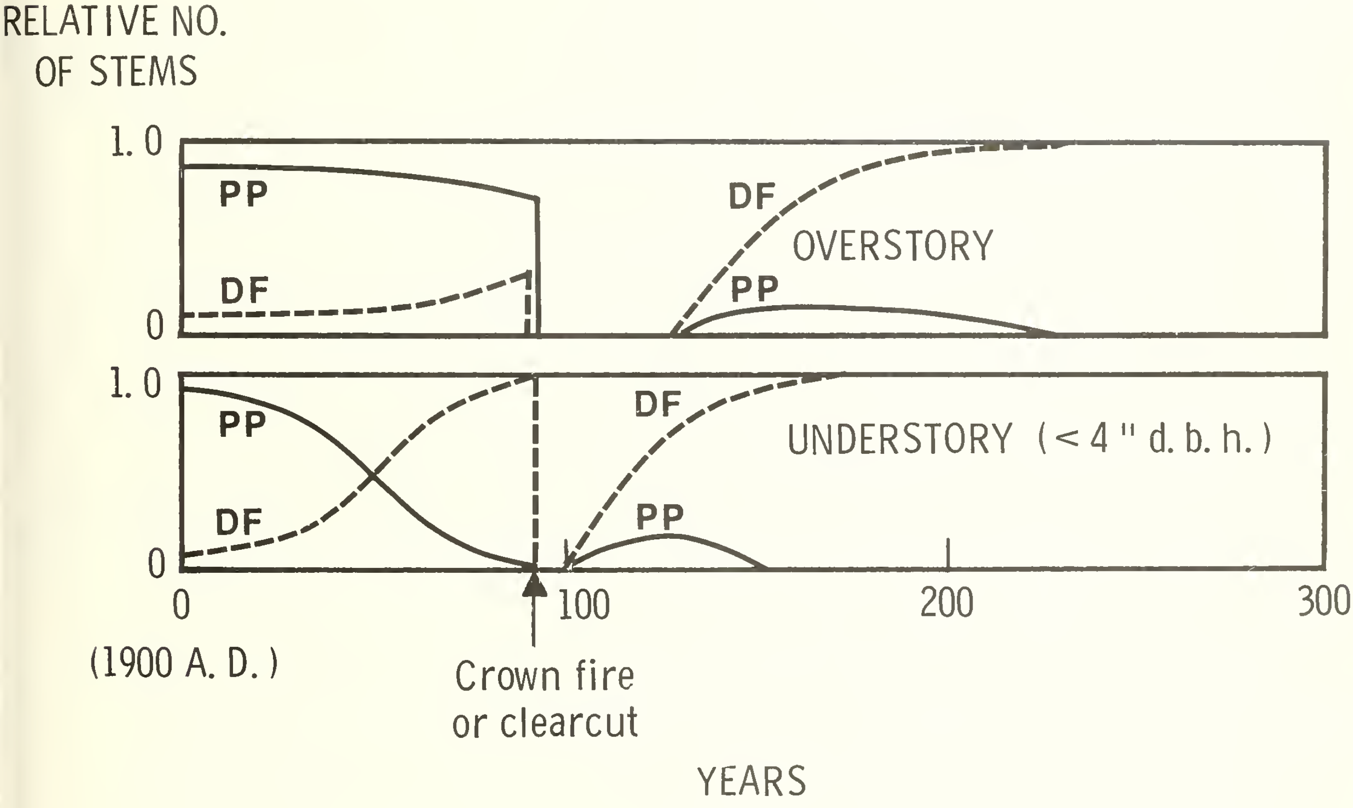
Case 2.—Natural Succession With Fire Suppression and No Cutting

This diagram represents the succession that typically occurs with fire suppression in the same type of primeval stand. After about 50 years without fire, Douglas-fir has become the understory dominant because of its greater shade tolerance. Ponderosa pine fails to regenerate and replace itself; thus the stand is converted to nearly pure Douglas-fir in 300 years.



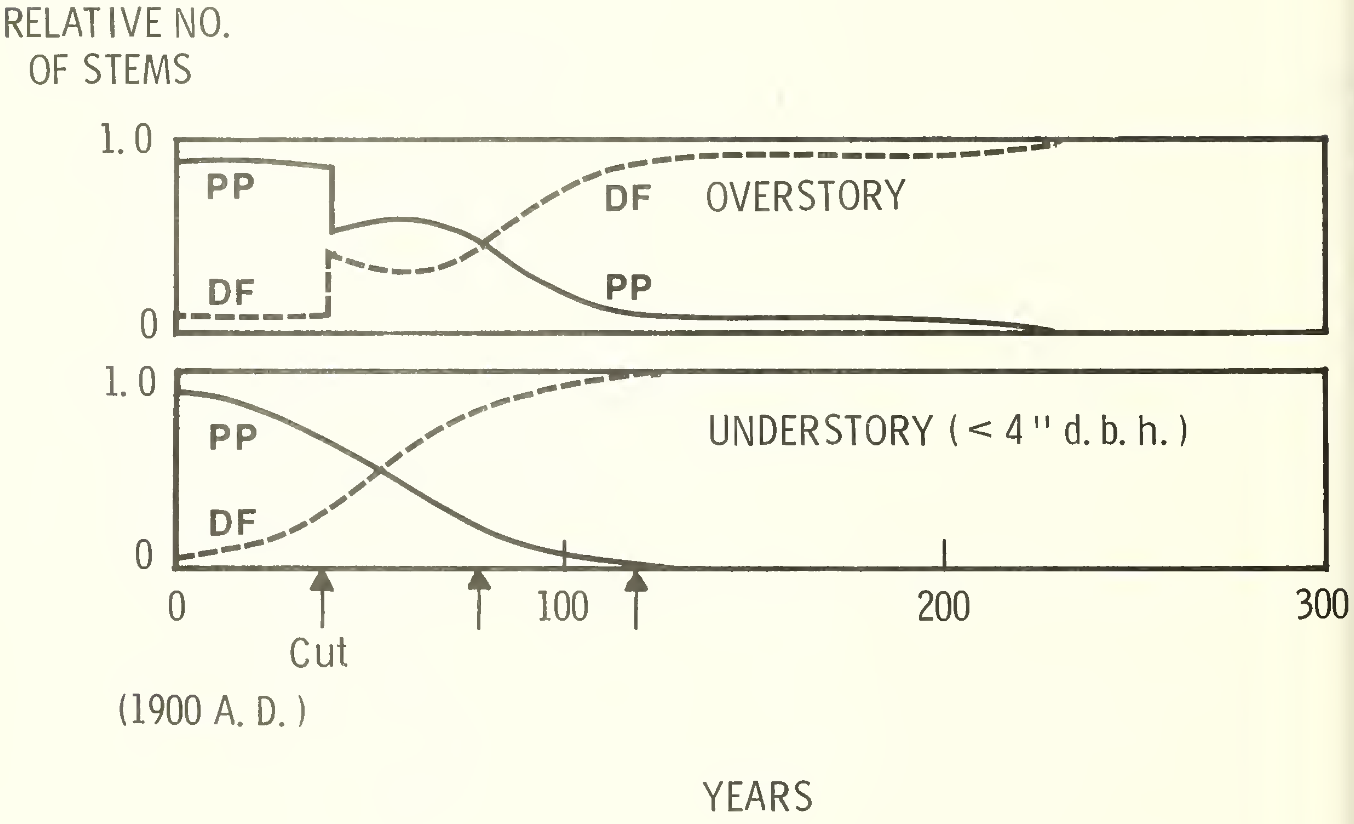
Case 3.—Stand-Replacing Fire or Clearcut Imposed on Case 2

The dense growth of understory Douglas-fir, resulting from fire suppression, forms a fuel ladder that allows a wildfire to crown and destroy the stand in year 90. Or, a clearcutting treatment is applied, followed by natural regeneration. After either of these stand-replacing treatments, Douglas-fir regenerates more abundantly than ponderosa pine. This results because Douglas-fir has lighter seeds that disperse readily from adjacent stands and the species is more shade tolerant than pine, allowing it to eventually regenerate even in shrub thickets. (The treatment reduces the total number of stems to zero, which is depicted in the relative number of stems.)



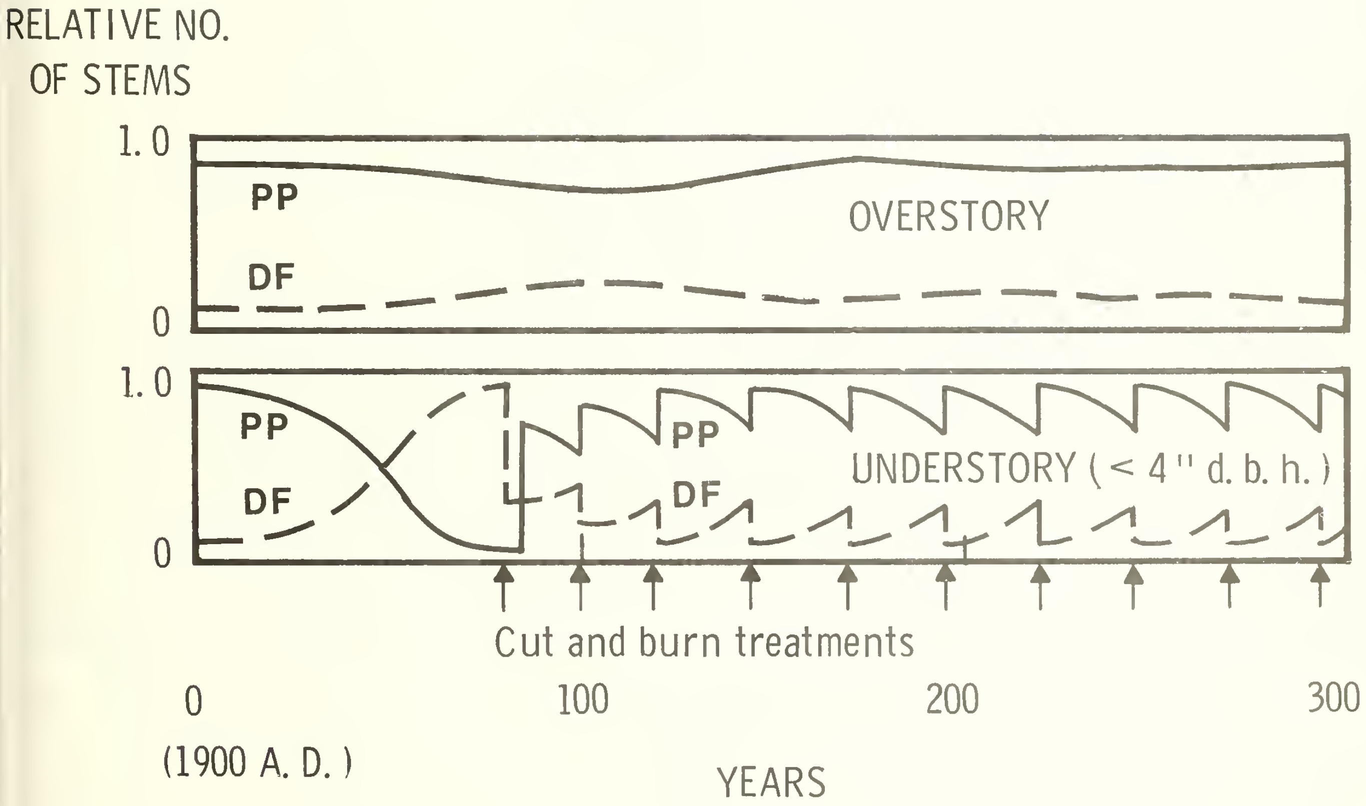
Case 4.—Selection Cutting Without Burning (Speed-up of Natural Succession)

The figure depicts a series of selective cuttings in which the large ponderosa pine are favored for harvest because of their high value. The first cutting is made 40 years after the last understory fire. Because no appreciable site preparation or burning accompanies the cutting, Douglas-fir regeneration is favored. Succession to Douglas-fir forest is accelerated by this type of cutting in the absence of understory fire. A dramatic example of this case is shown in photographs taken over a 39-year period in Gruell and others (1982, page 32).



Case 5.—Selection Cutting With Underburning to Favor Ponderosa Pine

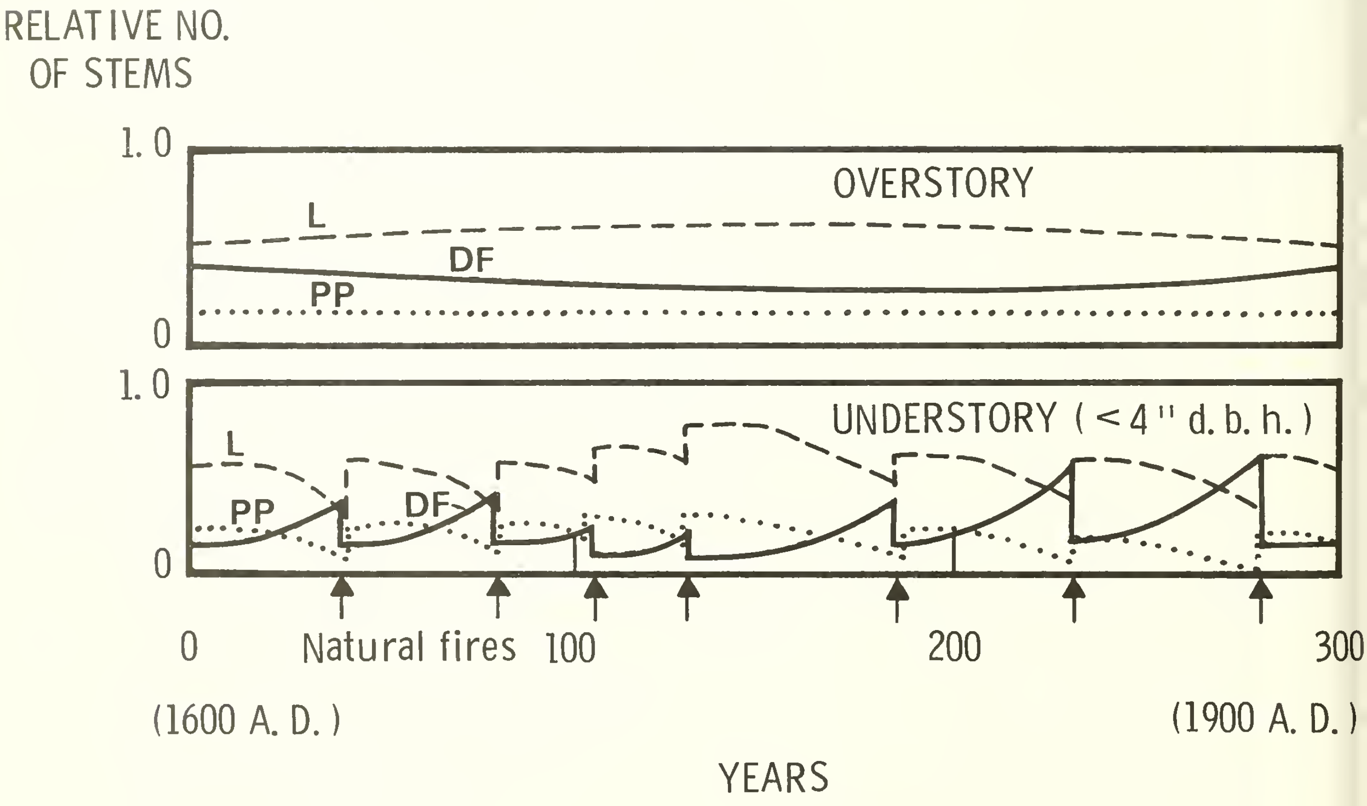
The hypothesized effects of selection cutting and prescribed underburns intended to favor regeneration of ponderosa pine are shown. The stand-opening cuttings and site-preparing burns were begun 80 years after the last understory wildfire. Most of the overstory Douglas-fir is removed in each cutting, while pines are left as a seed source. Larger proportions of understory Douglas-fir are killed with each treatment than ponderosa pine; thus, the result is a silviculturally perpetuated PP-DF forest that closely resembles the presettlement situation (case 1). A shelterwood cutting-underburn treatment could also be applied to perpetuate ponderosa pine through natural regeneration.



APPENDIX D-2.—HYPOTHESIZED TREE SUCCESSION ON THE PSME/PHMA, MOIST PHASE

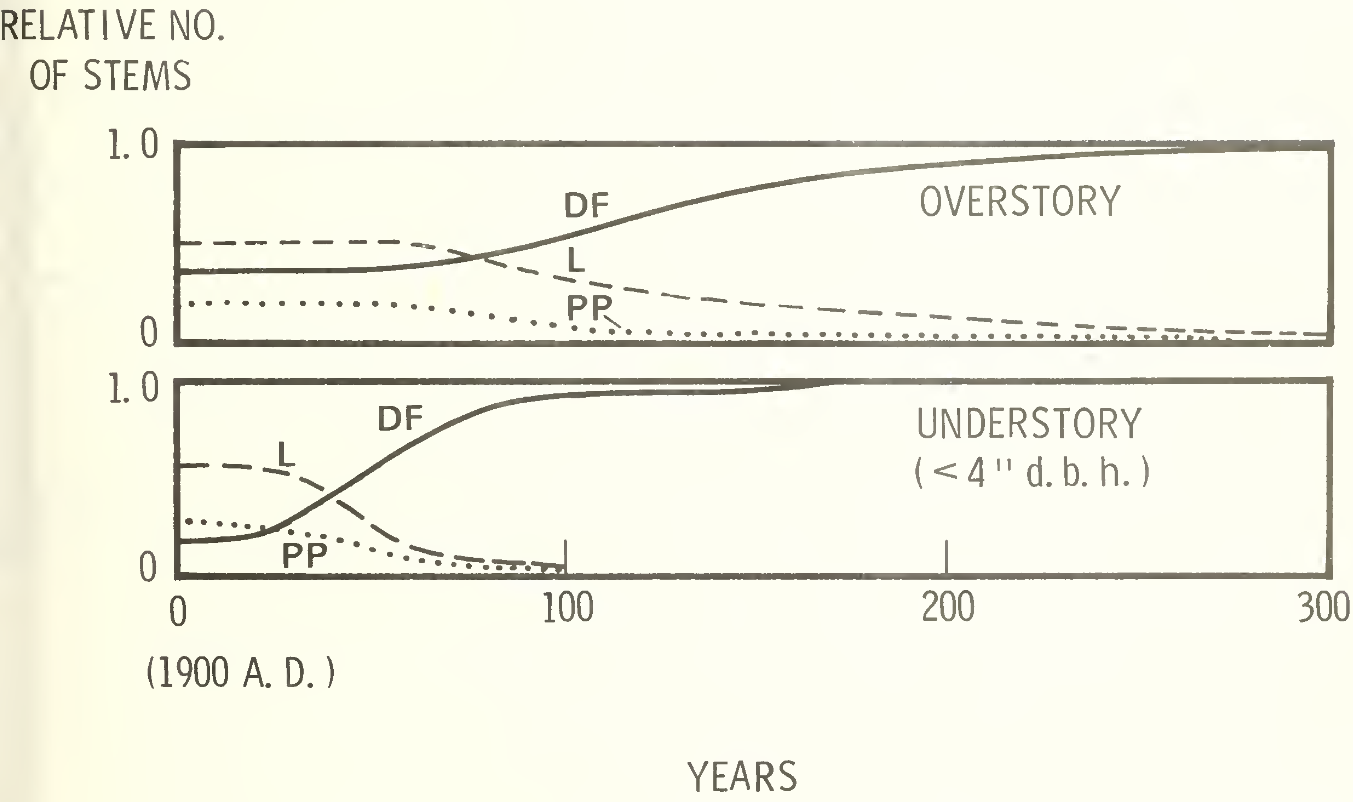
Case 1.—Natural Succession With Understory Fires

This figure shows a common pattern of tree succession in a pre-1900 stand in the moist phase. Low- to medium-intensity surface fires occurred at 10- to 50-year intervals, continually favoring western larch (L) and ponderosa pine (PP) by killing a high proportion of the Douglas-fir (DF) regeneration. Larch and ponderosa pine saplings are less vulnerable to light fires than Douglas-firs of comparable age. This fire regime maintained mixed, open stands of large larch, Douglas-fir, and ponderosa pine, with a patchy regeneration layer. Lodgepole pine is sometimes a minor component of this phase, but is not shown in this illustration.



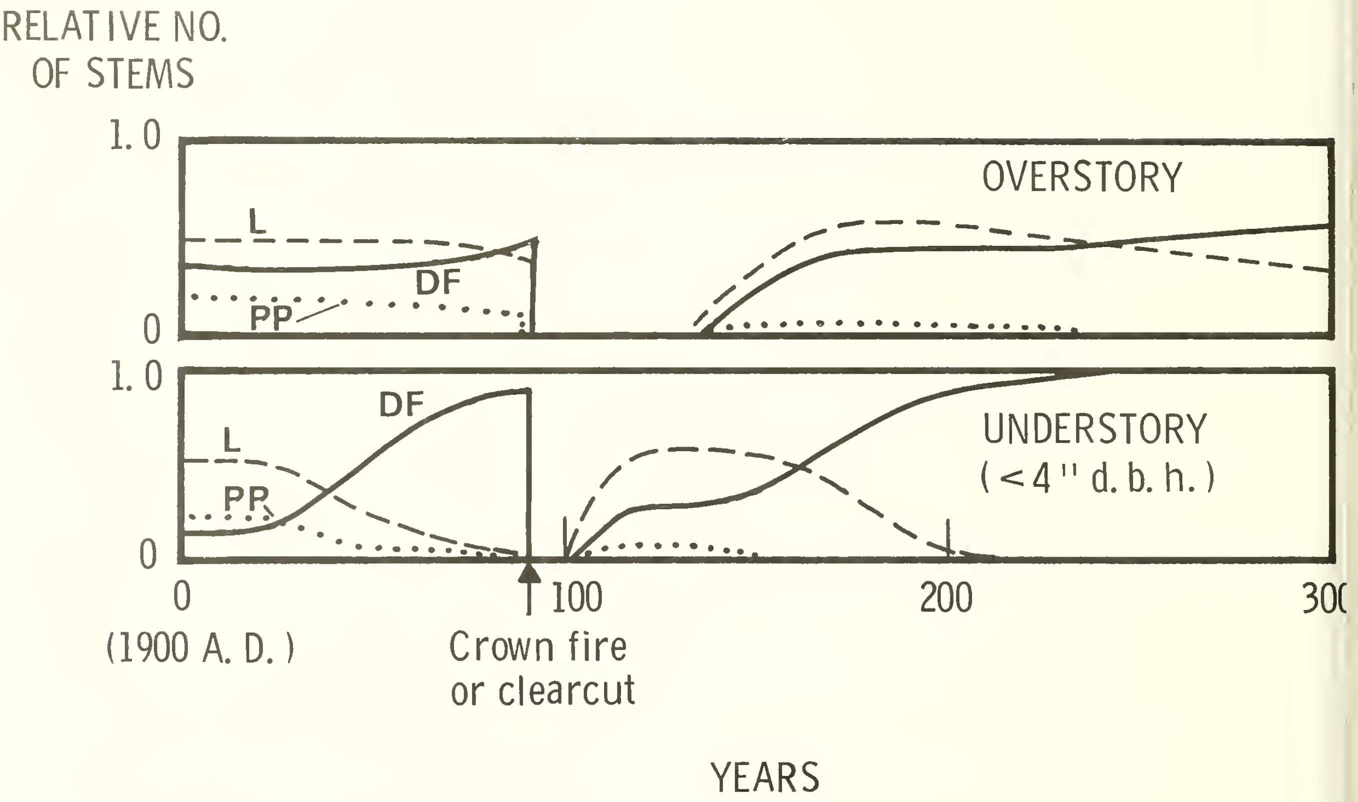
Case 2.—Natural Succession With Fire Suppression and No Cutting

This represents succession that occurs with fire suppression in the same type of primeval stand as in case 1. After about 50 years without fire, Douglas-fir has become the understory dominant because of its greater shade tolerance. Larch and ponderosa pine fail to regenerate and replace themselves; thus the stand is converted to nearly pure Douglas-fir by year 300. Partial cutting without scarification or underburning will tend to accelerate this succession to Douglas-fir.



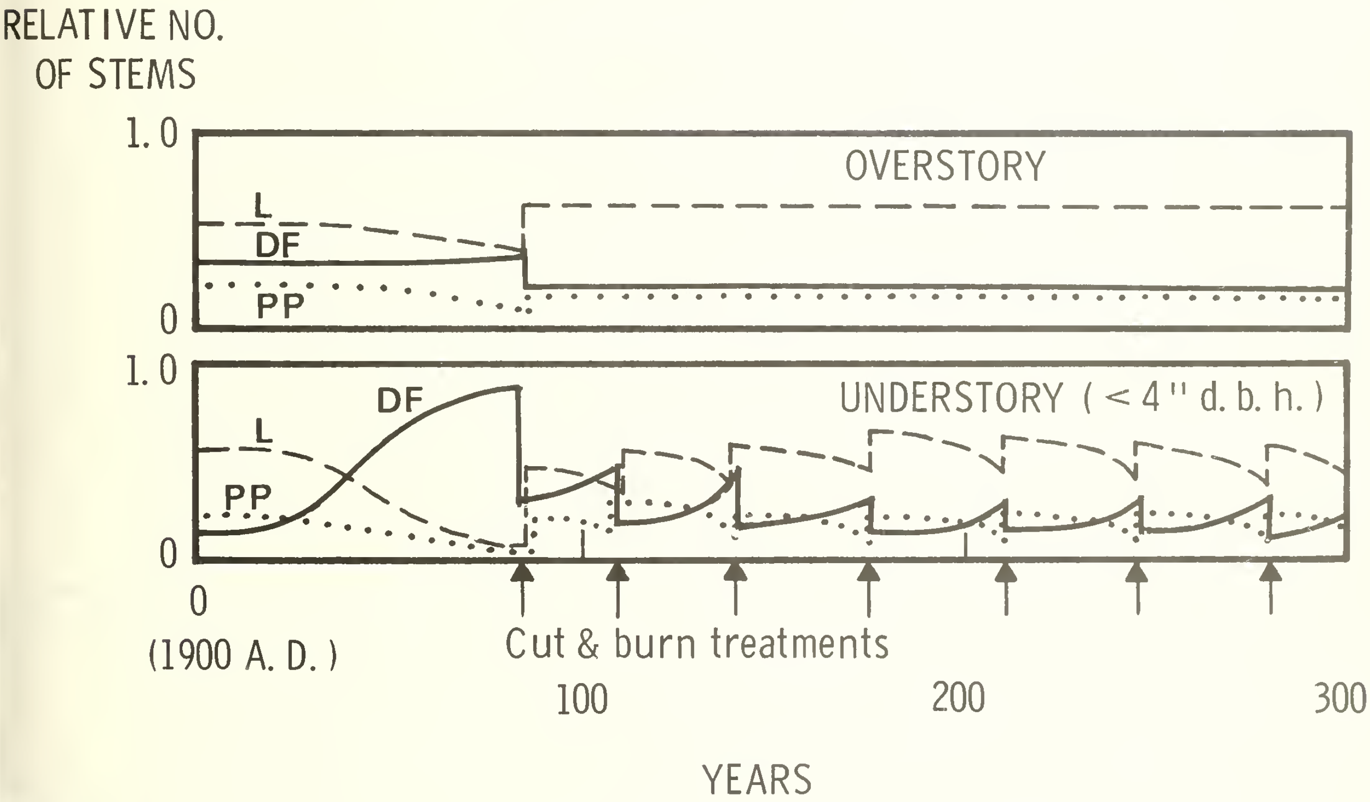
Case 3.—Stand Replacing Fire or Clearcut Imposed on Case 2

A severe wildfire or a clearcutting treatment occurs. Afterwards, larch and Douglas-fir, having lighter seeds that disperse readily from adjacent stands, regenerated much more abundantly than the heavy seeded ponderosa pine. (The treatment reduces the total number of stems nearly to zero, which is depicted in the relative number of stems.)



Case 4.—Selection Cutting With Underburning to Favor Larch and Ponderosa Pine

Hypothesized effects are shown for a silvicultural system of selection cutting and prescribed underburns intended to favor regeneration of larch and ponderosa pine. The stand-opening cuts and site-preparing burns were begun 80 years after the last understory wildfire. Larger proportions of understory Douglas-fir are killed with each treatment and, unlike clearcuts or stand-destroying fires, this treatment retains a ponderosa pine seed source. The result is a silviculturally perpetuated L-DF-PP forest that resembles the presettlement situation (case 1). A shelterwood cutting-underburn treatment could also be applied to perpetuate larch and ponderosa pine through natural regeneration.



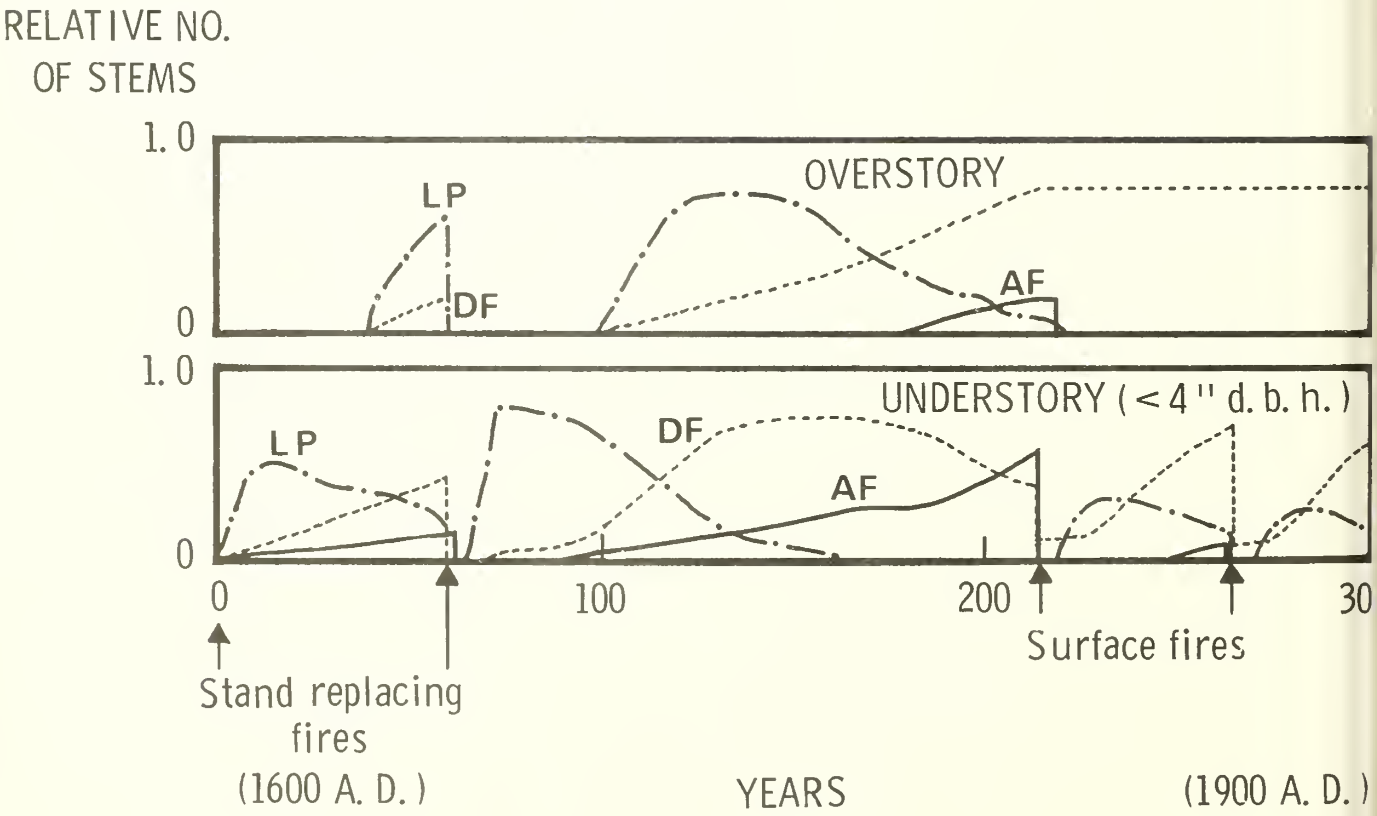
APPENDIX D-3.—THE PSME/VAGL, XETE PHASE

Hypothesized successional patterns of tree species are not presented for the PSME/VAGL, XETE phase; however, such patterns would parallel those shown for ABLA/XETE, VAGL phase if subalpine fir were deleted.

APPENDIX D-4.—HYPOTHESIZED TREE SUCCESSION ON THE ABLA/XETE, VAGL PHASE

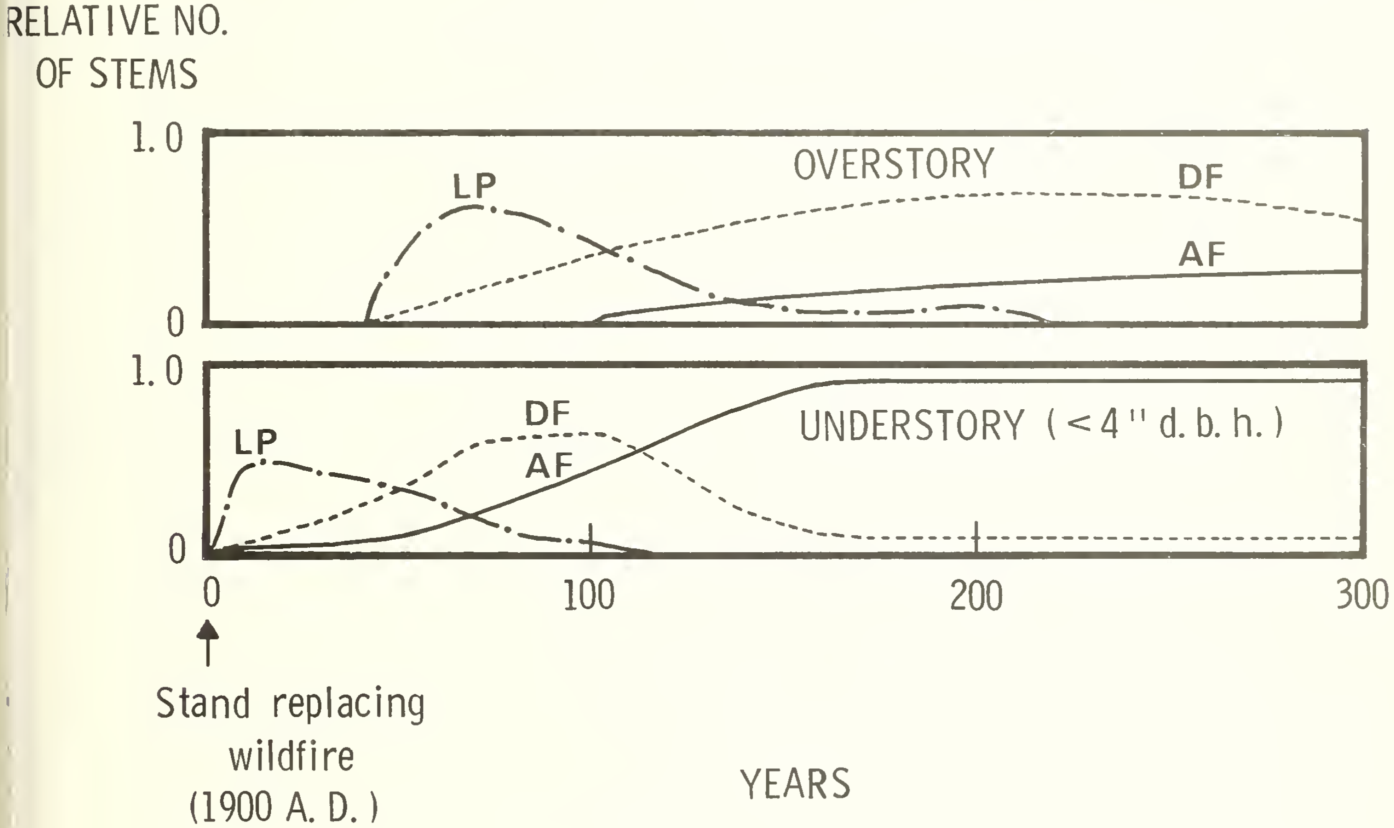
Case 1.—Natural Succession With Pre-1900 Wildfires

The figure shows a pattern of tree succession in a pre-1900 stand in which both stand-replacing fires and lower intensity surface fires occurred at various intervals (Arno 1980). Lodgepole pine (LP) was favored by fires, as was Douglas-fir (DF) to a lesser extent. Subalpine fir (AF), a shade-tolerant species, is killed by any fire and requires more than a century to regain dominance after fire. Most pre-1900 stands had overstories of Douglas-fir and lodgepole pine. Understories contained subalpine fir in addition to the other species. Underburning perpetuated open stands of large Douglas-fir and sometimes western larch. Stand-replacing fires favored lodgepole pine and sometimes larch. (The crown fire reduces the total number of stems to zero, which we have depicted in the relative number of stems.)



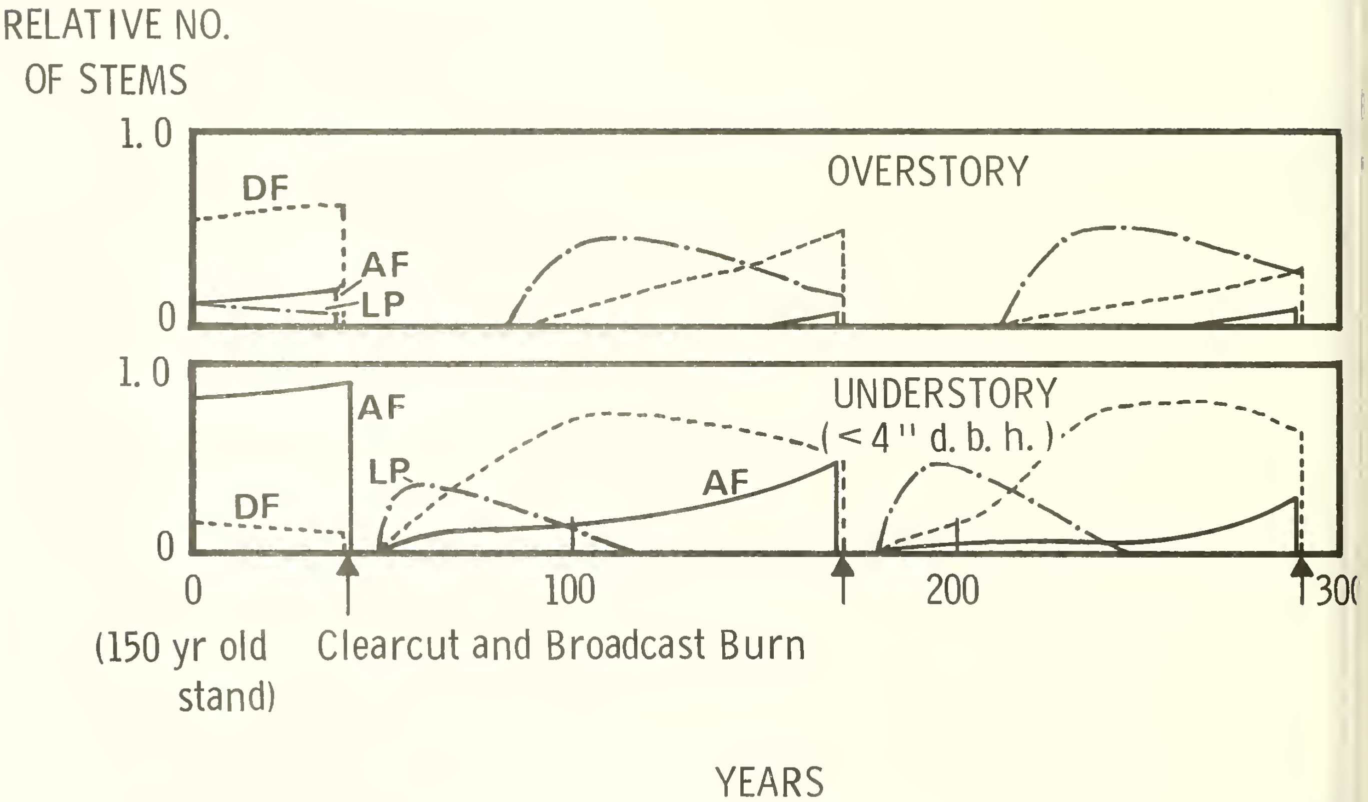
Case 2.—Natural Succession With Fire Suppression and No Cutting

Without disturbances, lodgepole pine fails to regenerate, allowing Douglas-fir to become the overstory dominant 125 to 150 years after the last fire. Subalpine fir becomes the dominant understory and eventually becomes a codominant in the overstory with Douglas-fir. Partial cutting without burning or scarification tends to speed up this natural succession. (The crown fire reduces the total number of stems to zero, which is depicted in the relative number of stems.)



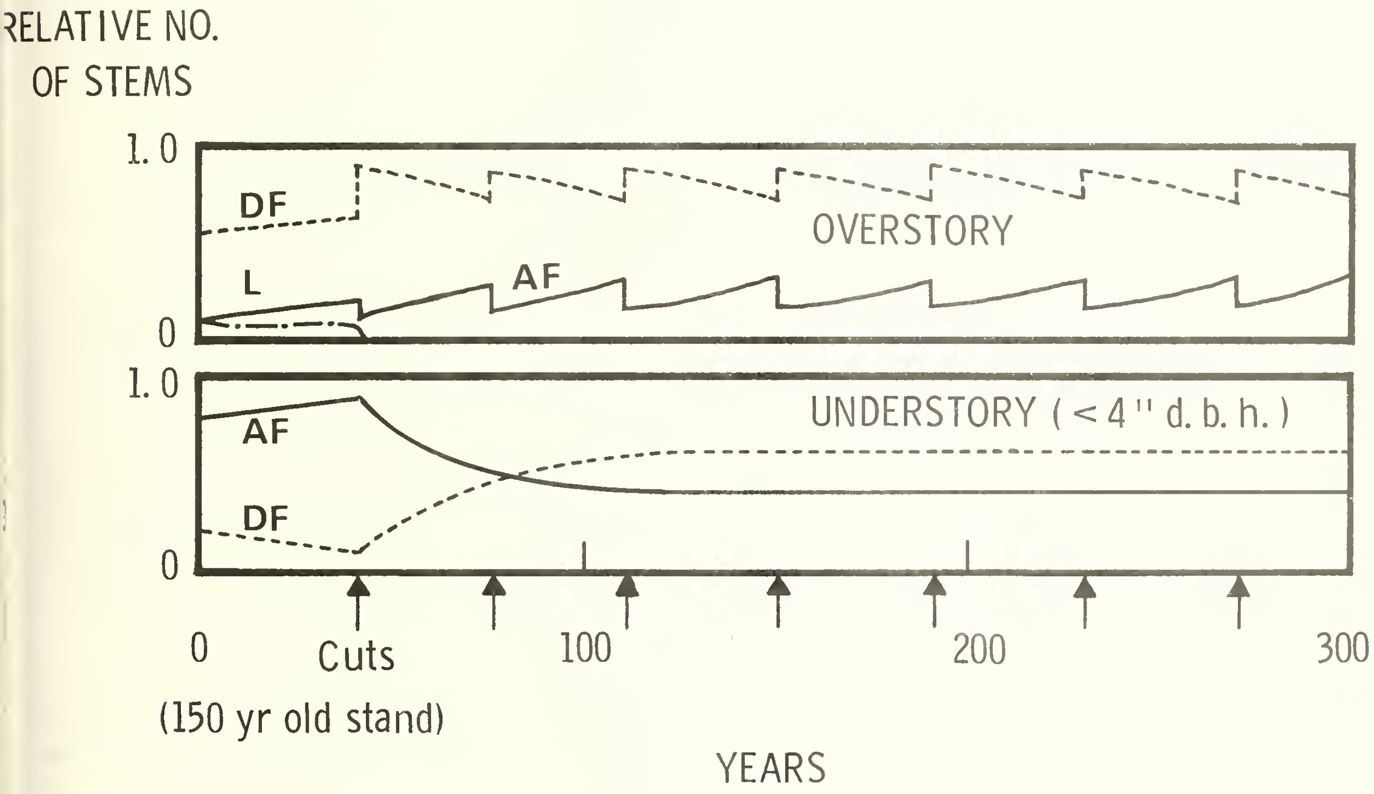
Case 3.—Clearcutting with Broadcast Burning

This treatment is most favorable for lodgepole pine, which increases relative to Douglas-fir through successive rotations. Subalpine fir remains a minor understory component. (The treatment reduces the total number of stems to zero, which is depicted in the relative number of stems.)



Case 4.—Selection Cuttings

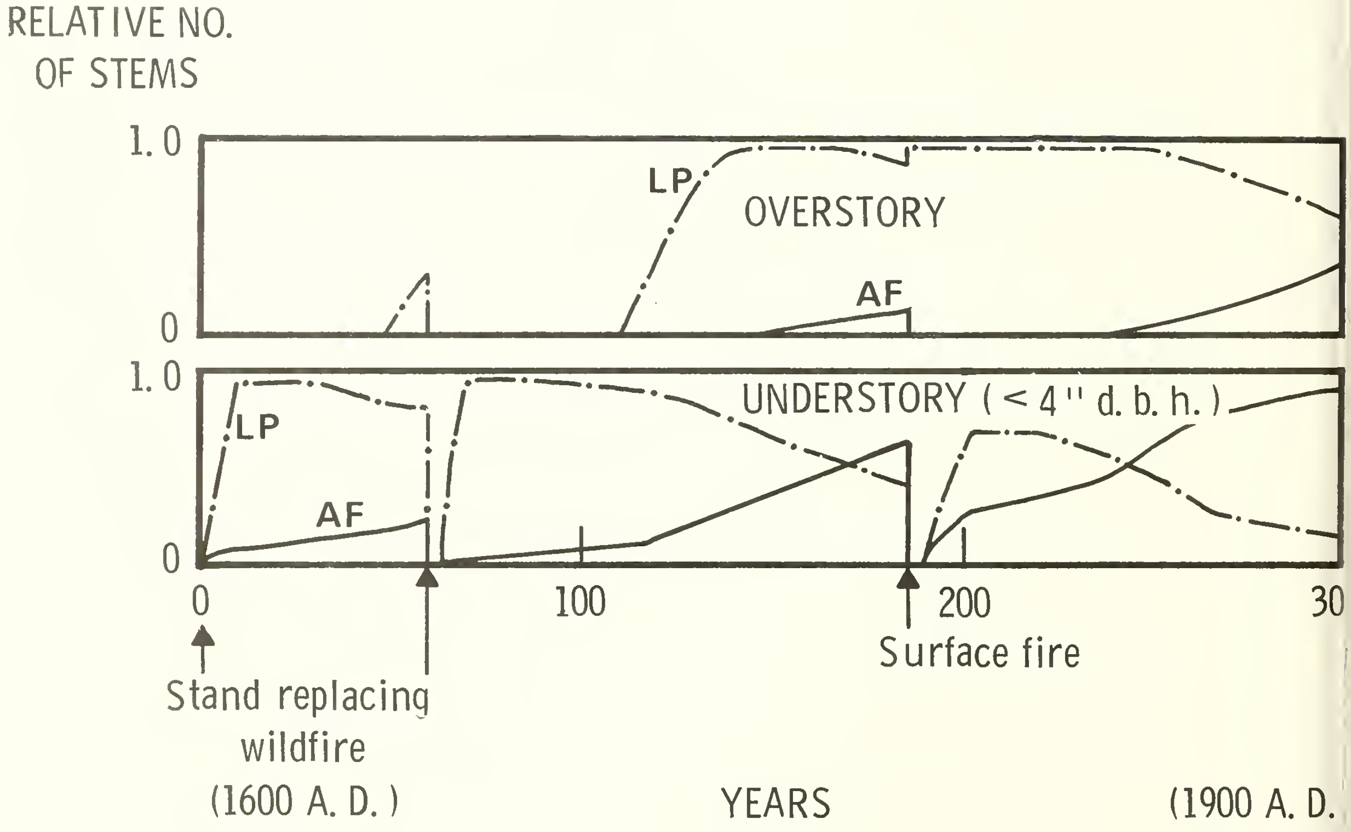
Cuttings are made (at 40-year intervals) to favor Douglas-fir. All subalpine firs greater than 4 inches in d.b.h. are harvested or felled with each cutting in order to remove this seed source. Slash concentrations are burned in piles or jackpots. Douglas-fir (and larch if present) regeneration is benefited by the stand-opening cuts, burned areas, and skid trails. This species' faster growth enables it to maintain overstory dominance over subalpine fir with continued cutting treatments.



APPENDIX D-5.—HYPOTHESIZED TREE SUCCESSION ON THE ABLA/XETE, VASC PHASE

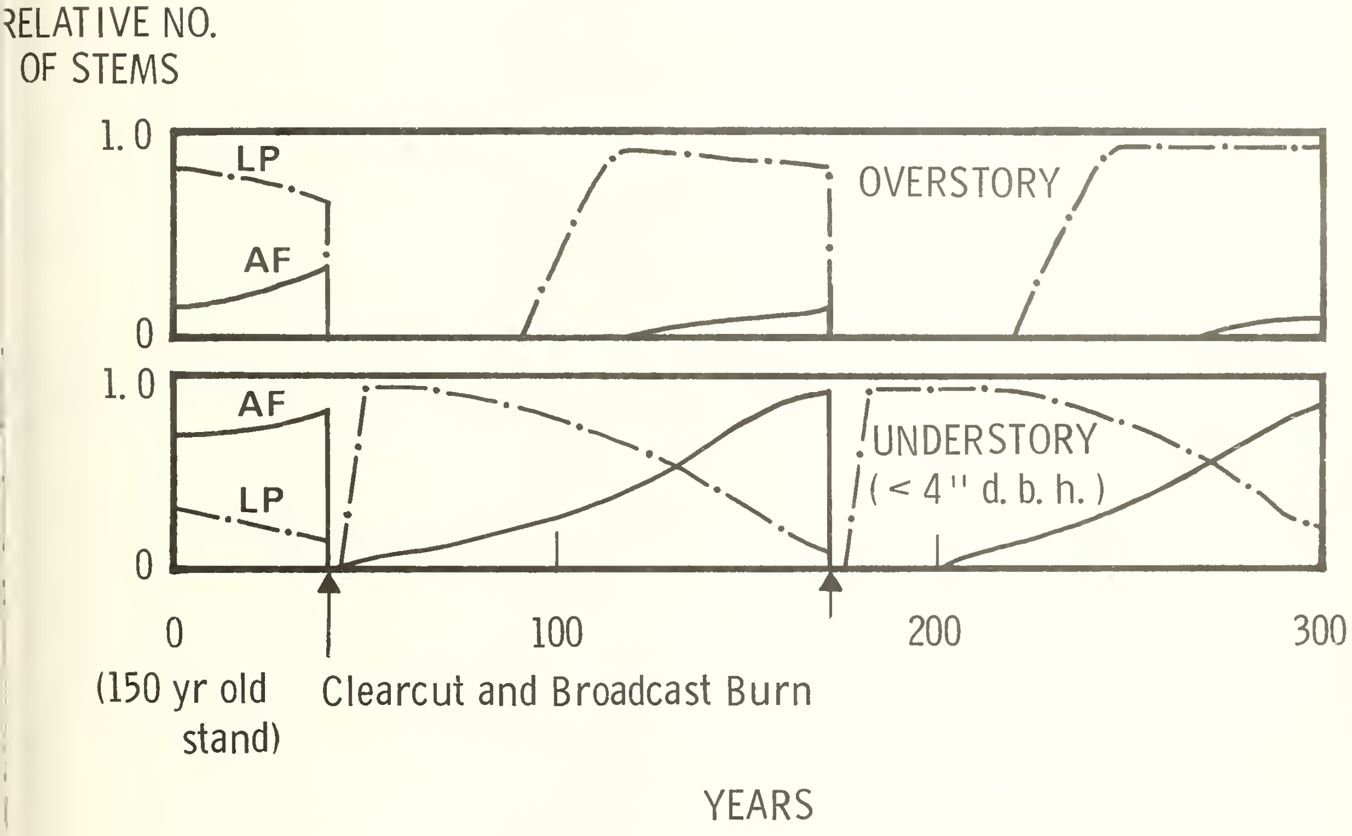
Case 1.—Natural Succession With Pre-1900 Wildfires

Both stand-replacing fires and less intense surface fires occurred at various intervals (Arno 1980). Lodgepole pine was favored by fire treatments, whereas subalpine fir became the climax dominant after 200 years or more without fire. Douglas-fir, Engelmann spruce, and whitebark pine are minor components in this phase that are not shown in this illustration. Fire suppression or partial cutting tends to favor succession to dominance by subalpine fir. (The crown fire reduces the total number of stems to zero, which is depicted in the relative number of stems.)



Case 2.—Clearcutting with Broadcast Burning or Other Site Preparation Treatments

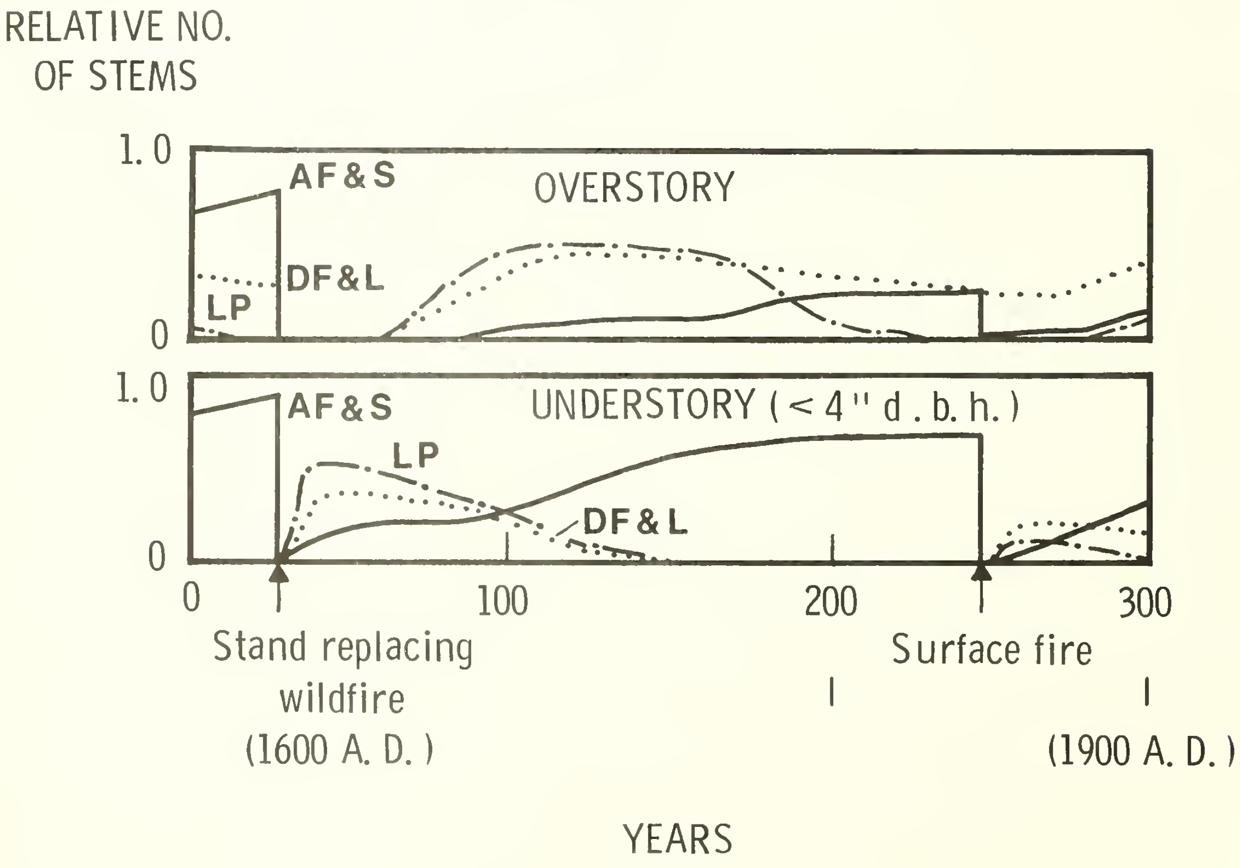
These treatments are made every 130 years, and this results in development of nearly pure lodgepole pine overstories. Clearcutting carried out without burning or site preparation would generally result in stands dominated by lodgepole pine and subalpine fir. (The treatment reduces the total number of stems to zero, which is depicted in the relative number of stems.)



APPENDIX D-6.—HYPOTHESIZED TREE SUCCESSION ON ABLA/MEFE, WARM PHASE

A common successional pattern is depicted for pre-1900 stands. To simplify the diagram, subalpine fir (AF) and Engelmann spruce (S) are combined. (Their successional differences are shown in appendix C-7 representing the cold phase of ABLA/MEFE.) Douglas-fir (DF) and western larch (L) are long-lived intolerant species in this habitat type and are also combined. Two types of wildfires occurred. The stand-replacing fire gave rise to vigorous regeneration of lodgepole pine (LP), DF, and L, with lesser amounts of AF and S. This developed into a dense pole stand of seral species. When the LP component of this stand died (150 to 180 years after the fire), AF and S replaced it. A moderate surface fire occurred in the mature seral forest and killed most of the fire-susceptible trees, leaving the overstory DF, L, and a few S. A modest amount of regeneration of all species, except perhaps L, occurred after the surface fire.

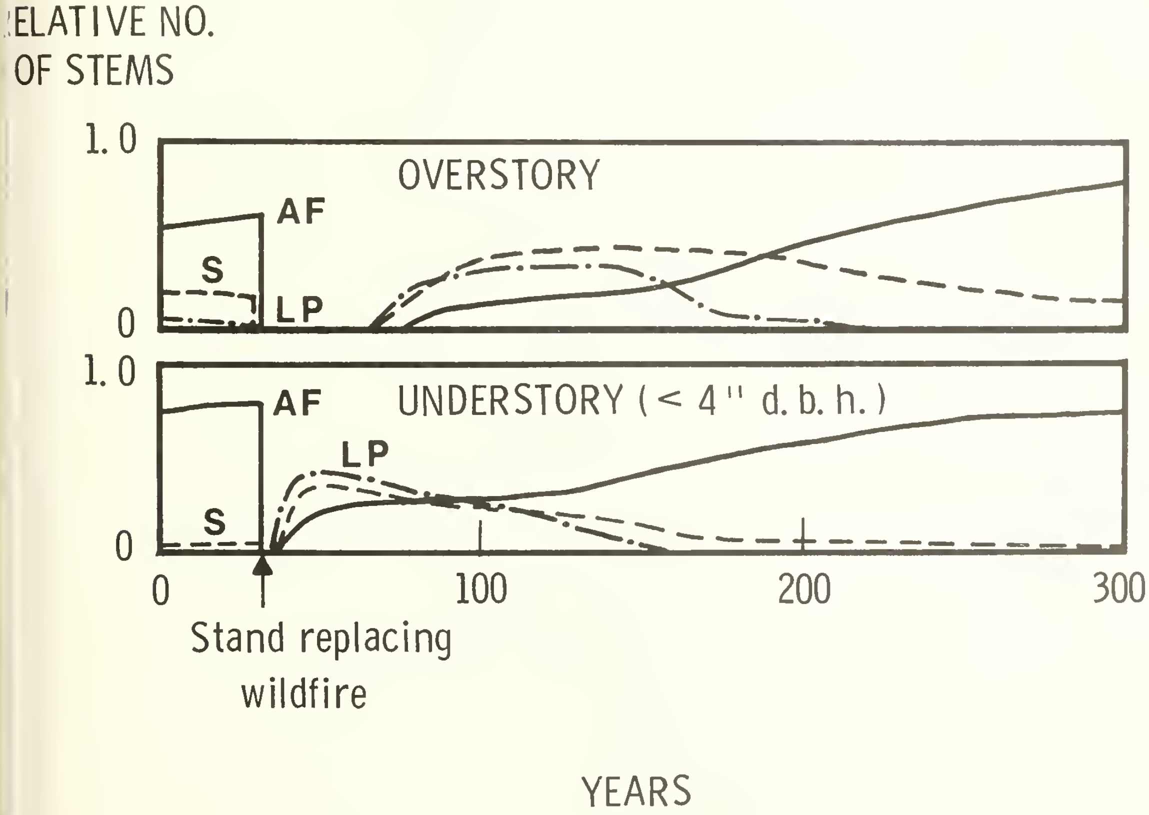
Fire suppression and partial cutting without site preparation will allow subalpine fir to develop into the climax dominant species. The crown fire reduces the total number of stems to zero, which is depicted in the relative number of stems.



.PPENDIX D-7.—HYPOTHESIZED 'REE SUCCESSION ON ABLA/MEFE, 'OLD PHASE

A common successional pattern is shown in pre-1900 ands. A stand-replacing fire occurred in a 150-year-old and having seed from serotinus cones in a few living dgepole pine (LP) and snags. After the fire, LP and ›ruce (S) dominate the young stand. LP dies about 150 ›ars after the fire, and subalpine fir (AF) steadily in- eases in abundance. In the 300-year-old stand (right ge), S is slowly being replaced by the more shade- lerant AF.

Partial cutting without site preparation would presum- ıly speed up this succession. Clearcutting with site eparation would generally restart this sort of succes- ›nal pattern, provided that a seed source for the seral ecies remained. (The crown fire reduces the total num- r of stems to zero, which is depicted in the relative ımber of stems.)



APPENDIX E.—SUCCESSION CLASSIFICATION FIELD FORM FOR HABITAT TYPES PSME/PHMA, PSME/VAGL, ABLA/XETE, ABLA/MEFE

OBSERVER:	DATE:	Elevation		
HABITAT TYPE:	Site No.:	Slope		
PHASE:		Aspect		

Canopy Coverage Class codes:
0 = absent 2+ = 20 - 25%
T = 1% 3 = 25 - 50%
1 = 1 - 5% 4 = 50 - 75%
2- = 5 - 10% 5 = 75 - 95%
2 =10 - 20% 6 = 95 - 100%

Treatment codes:
NP = Clearcut and no site prep.
BB = CC & Broadcast Burn
MS = CC & Mechanical Scarification
MSB = CC & MS and burning
WF = Stand replacing wildfire

Intensity codes:
L = Light or Low
M = Medium
H = Heavy or High

Location: T____ R____ S____ ¼ sec. ____
Description: ____

	untreated(mature)	treated	treated
STAND Letter	A	B	C
STAND Characteristics:			
1. Total canopy coverage of all trees (percent)			
2. Average d.b.h. of dominant trees (inches)			
3. Basal area per acre (square feet)			
4. Year of treatment or major disturbance			
5. Treatment Type/Intensity (codes from above)	/	/	/
6. Bare mineral soil exposed (percent)			

TREES: Scientific Names	Abbrev.	Common Names	Coverage codes for overstory/understory (<4" dbh)		
1. Abies lasiocarpa	ABLA	subalpine fir	/	/	/
2. Larix occidentalis	LAOC	western larch	/	/	/
3. Picea engelmannii	PIEN	Engelmann spruce	/	/	/
4. Pinus albicaulis	PIAL	whitebark pine	/	/	/
5. Pinus contorta	PICO	lodgepole pine	/	/	/
6. Pinus ponderosa	PIPO	ponderosa pine	/	/	/
7. Pseudotsuga menziesii	PSME	Douglas fir	/	/	/
8.			/	/	/

SHRUBS and SUBSHRUBS: (Include other species with 5% coverage or greater)				Coverage codes	
1. Acer glabrum	ACGL	mountain maple			
2. Alnus sinuata	ALSI	Sitka alder			
3. Amelanchier alnifolia	AMAL	serviceberry			
4. Ceanothus canguineus	CESA	redstem ceanothus			
5. Ceanothus velutinus	CEVE	evergreen ceanothus			
6. Menziesia ferruginea	MEFE	Menziesia			
7. Physocarpus malvaceus	PHMA	ninebark			
8. Ribes viscosissimum	RIVI	sticky currant			
9. Rubus parviflorus	RUPA	thimbleberry			
10. Salix scouleriana	SASC	Scouler willow			
11. Spiraea belulifolia	SPBE	white spirea			
12. Symphoricarpos albus	SYAL	common snowberry			
13. Vaccinium globulare	VAGL	blue huckleberry			
14. Vaccinium scoparium	VASC	grouse whortleberry			
15.					
16.					

GRASSES: (include other species with 5% coverage or greater)					
1. Calamagrostis rubescens	CARU	pinegrass			
2. Carex geyeri	CAGE	elk sedge			
3. Carex rossii	CARO	Ross sedge			
4. Carex concinnoides	CACO	northwestern sedge			
5.					

FORBS: (include other species with 5% coverage or greater)					
1. Anaphalis margaritacea	ANMA	pearly everlasting			
2. Arnica latifolia	ARLA	broadleaf anica			
3. Chimaphila umbellata	CHUM	prince's pine/pipsissewa			
4. Epilobium angustifolium	EPAN	fireweed			
5. Xerophyllum tenax	XETE	beargrass			
6.					
7.					

WET SITES SPECIES: (include other species with 5% coverage or greater)					
1. Calamagrostis canadensis	CACA	blue joint			
2. wet-site Carex	Carex	wet site sedges			
3. Cinna latifolia	CILA	drooping woodreed			
4. Deschampsia atropurpurea	DEAT	mountain hairgrass			
5. Juncus drummondii	JUDR	Drummond rush			
6. Senecio triangularis	SETR	arrowleaf groundsel			
7. Trollius laxus	TRLA	American globeflower			
8. Veratrum viride	VEVI	white hellebore			
9.					
10.					

Community Type			

*U.S. GOVERNMENT PRINTING OFFICE: 1985-0-576-040/10525

Arno, Stephen F.; Simmerman, Dennis G.; Keane, Robert E. Forest succession on four habitat types in western Montana. General Technical Report INT-177. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1985. 74 p.

Presents classifications of successional community types on four major forest habitat types in western Montana. Classifications show the sequences of seral community types developing after stand-replacing wildfire and clearcutting with broadcast burning, mechanical scarification, or no followup treatment. Information is provided for associating vegetational response to treatments.

KEYWORDS: forest succession, plant communities, vegetation modeling, forest ecology, fire effects

The Intermountain Station, headquartered in Ogden, Utah, is one of eight regional experiment stations charged with providing scientific knowledge to help resource managers meet human needs and protect forest and range ecosystems.

The Intermountain Station includes the States of Montana, Idaho, Utah, Nevada, and western Wyoming. About 231 million acres, or 85 percent, of the land area in the Station territory are classified as forest and rangeland. These lands include grasslands, deserts, shrublands, alpine areas, and well-stocked forests. They supply fiber for forest industries; minerals for energy and industrial development; and water for domestic and industrial consumption. They also provide recreation opportunities for millions of visitors each year.

Field programs and research work units of the Station are maintained in:

Boise, Idaho

Bozeman, Montana (in cooperation with Montana State University)

Logan, Utah (in cooperation with Utah State University)

Missoula, Montana (in cooperation with the University of Montana)

Moscow, Idaho (in cooperation with the University of Idaho)

Provo, Utah (in cooperation with Brigham Young University)

Reno, Nevada (in cooperation with the University of Nevada)

United States
Department of
Agriculture

Forest Service

Intermountain
Forest and Range
Experiment Station
Ogden, UT 84401

General Technical
Report INT-178

March 1985

An Application of Discrete Optimization for Developing Economically Efficient Multiple-Use Projects

J. Greg Jones
Ervin G. Schuster

THE AUTHORS

J. GREG JONES is a research forester with the Economics Research Work Unit, Forestry Sciences Laboratory, Missoula, MT. His research includes economic efficiency modeling for use in multiple-use management, measurement of multiple-use costs, and analysis of economic impact.

ERVIN G. SCHUSTER is a research forester and project leader of the Economics Research Work Unit, Forestry Sciences Laboratory, Missoula, MT. His research includes modeling of timber harvesting, measurement of nontimber outputs, and analysis of economic impact.

RESEARCH SUMMARY

This paper presents a model formulation useful (1) for planning multiple-use projects and (2) for identifying efficient management prescriptions and/or aggregate emphasis projects to build into future forest planning models. The formulation is a discrete version of the continuous joint production model in economic theory. Economic efficiency can be analyzed both in terms of type of project and scale of project.

The model can be formulated and solved graphically or as a mixed-integer programming (MIP) problem. The graphic approach rather clearly depicts the nature of economic efficiency in multiple-use production and requires little in the way of equipment. It is, however, limited to problems that can be depicted in two-dimensional space. The MIP approach has the following advantages over the graphic approach: (1) it can accommodate more than two outputs, (2) intertemporal analysis is easier to conduct, (3) capability to conduct sensitivity analysis is enhanced, and (4) it lends itself well to automation.

The MIP formulation contains decision variables that are formulated as whole decision alternatives, which assume values of 0 (do not do project) or 1 (do project). This differs from mathematical programming formulations common in forestry (for example, FORPLAN, MUSYC, and Timber RAM) in which decision variables are formulated on a per-acre basis. The advantages of the MIP formulation are that diminishing marginal productivity can be modeled and the level of site specificity is enhanced. The main disadvantage of this MIP approach is that only a limited number of management alternatives can be handled effectively, making it best suited to problems of a relatively small geographic scope, for example, a project planning area.

The MIP formulation is easy to solve and sufficiently small to be processed on a small computer. Combined with front-end data processing software, it could be useful for conducting multiple-use efficiency analysis. The potential lies not as a substitute for current forest planning methods, but rather as a tool to aid in identifying efficient management prescriptions to place in forest planning models and as a means of analyzing projects for implementation.

An Application of Discrete Optimization for Developing Economically Efficient Multiple-Use Projects

J. Greg Jones
Ervin G. Schuster

ITRODUCTION

n recent history, the focus of land management eco- rmic analysis on National Forests has been in forest pinning. Large-scale planning models, such as IRPLAN (Gilbert and others 1982), are being used to cnduct economic analysis of multiple-use management i this planning process. For a variety of reasons, how- eer, forest planning analysis has to be conducted at a ratively low level of resolution. As a result, there may b many spatial configurations and timing sequences for iplementing the general management direction identi- fd in forest planning.

There remains a need for economic analysis in project csign to aid in identifying projects that efficiently im- p ment forest plans. Clearly, if projects are not effi- cnt, overall management will not be efficient, because pojects are the means by which management is im- pmented on the ground. Unfortunately, economics of poject planning has largely been ignored by economists ad analysts. As a result analytical techniques or models f this purpose are lacking. This may be particularly ctical for projects with considerable multiple-use com- pnents, where efficient designs are particularly difficult t identify.

n this paper we present a model formulation we be- lve may be useful in planning multiple-use projects. In adition, it could have application in identifying efficient rnagement prescriptions and/or aggregate emphasis pojects to build into FORPLAN models in future forest pnning efforts.

First, the model is presented in graphical terms for a hpothetical but realistic project planning situation. Ixt, a mixed-integer mathematical programming formu- lion of the model is presented and solved. Then, sensi- tity analysis techniques applicable to the mixed-integer pgramming formulation are discussed. Finally, several tpics are discussed regarding the operational feasibility c this formulation.

THE CONCEPT

Gregory (1955) presented the case that an appropriate economic formulation for multiple use is the joint production model in microeconomic theory. Joint production occurs when two or more outputs are produced simultaneously (jointly) by a single production process, meat and hides, for example. The joint production model is comprised of a "production surface," which identifies the combinations of outputs that can be produced on a tract of land (or by some fixed production plant), given efficient use of variable inputs. For the two-output case, this production surface is often depicted by a series of "iso-cost" (or constant cost) lines. Each corresponds to a unique level for variable cost, and identifies the combinations of outputs that can be produced with that cost. Unit values for outputs are then introduced to find: (a) the combination of outputs on each iso-cost curve that provides the greatest total value and (b) which of these best points (the expansion path) maximizes net benefit.

The joint production model appears to fit multiple-use management, where the intention is to produce multiple outputs from a tract of land. The problem with applying this theoretical model is that it is not yet operationally feasible in a real-world planning situation. A major impediment is the lack of adequate continuous mathematical functions relating variable cost to the quantities of outputs that can be jointly produced (the production surface).

The formulation we present is a discrete version of Gregory's joint production model that builds on an approach suggested by Muhlenberg (1964). It is comprised of a finite number of points that approximate the continuous production surface of the theoretical model. These points are believed to be more operationally feasible to estimate than continuous mathematical production relationships. Yet, this discrete formulation provides the same type of analysis as the continuous model.

MODEL FORMULATION

We shall illustrate this discrete formulation of the theoretical joint production model by employing a simple but realistic example. The example pertains to a hypothetical 4,000-acre (1 619-ha) tract of forest land. This area is part of an important elk summer range and is currently overstocked with a homogeneous stand of low-quality but merchantable timber. The tree canopy is so dense that forage production is severely restricted and there is an excess of cover. The forest planning process has identified this area for a potential timber sale, the purpose of which is twofold: (1) to open up parts of the area to promote a better balance between cover and forage production and (2) to harvest timber to help meet the established cut goals for the forest.

The purpose of the model we present is to aid in identifying the type and scale of the timber sale project that most efficiently meets the two stated objectives. The scope of the problem is limited to project design. The planning horizon is 30 years—the length of time the cover/forage combination resulting from this management activity would be sustained. No additional harvests are scheduled for this area over the next 30 years. Finally, it is assumed that no other outputs from this area would be sufficiently affected as to warrant their inclusion in the model.

Before proceeding, we should make clear that the example we develop on the following pages is purely for illustrating the analytical approach. It would be inappropriate to generalize the management responses or subsequent results to other areas for several reasons. First, the results would be expected to be sensitive to existing conditions of an area, which could vary greatly. Second, appropriate output responses, costs, and unit values likely vary greatly as well.

The Alternatives

The five series of timber sale alternatives (A to E) presented in table 1 approximate the production surface for this problem. Each series reflects a specific theme, differing in the amount of emphasis given to promoting effective wildlife habitat on each acre harvested. Within a series, the alternatives employ common management practices and cutting unit design. Alternatives within a series differ only by the amount of harvesting that would be conducted, which is directly related to costs. Note that the first alternative in each series has a budget of $200,000, the second a budget of $400,000, and so on. A "no action" alternative (0) is also considered. It is used as a reference point against which output quantities and costs for the other alternatives are measured.

Series A.—These alternatives are designed to harvest timber at the lowest possible cost, thereby yielding the greatest net dollar return to the Federal treasury. These alternatives have relatively large cutting units (35 to 40 acres [12 to 16 ha]) located primarily on the basis of cost efficiency in logging and road building. All basic environmental constraints are satisfied, but no additional activities are undertaken for habitat improvement. Roads are left open and public use of the area is not restricted.

Series B.—These alternatives are the same as series A, except that the roads will be closed to motorized use by the public following harvest.

Series C.—The cutting units in these alternatives are distributed essentially the same as in the previously described alternatives. As in series B, the roads will be closed to public traffic. These alternatives differ mainly in that the logging slash will be broadcast burned to promote forage and browse production.

Series D.—These alternatives are characterized by smaller cutting units (average about 20 acres [8 ha]) with wildlife considerations being the primary basis for location. Roads will be closed to public access, and road slash will be cleaned up to eliminate its effect as a barrier to wildlife movement. Logging slash will be broadcast burned.

Series E.—These alternatives are designed to maximize wildlife benefits while still harvesting timber. The cutting units are either small or shaped to provide a good "edge effect." As in series D, roads will be closed, road slash will be cleaned up, and logging slash will be broadcast burned.

Outputs

Two outputs are included in the model: timber and summer range effectiveness. Both are measured in terms of marginal change from the "no action" alternative.

The quantity of timber is simply the volume that would be harvested under the alternatives (sixth column in table 1). Volume was assumed to be 8.5 M bd ft per acre across the 4,000-acre (1 619-ha) area. Although a constant volume per acre is not a requirement for this model, it is convenient for this example.

Summer range habitat effectiveness is measured in terms of change in the number of animals the 4,000-acre (1 619-ha) area can be expected to support annually (last column in table 1). In order to maintain as much simplicity as possible, carrying capacity response is expressed as an annual average over the planning horizon. Later, we shall discuss an approach for handling changing output response over time in the graphical formulation. Changing output quantities over time does not present any particular difficulty in the mixed-integer programming approach.

Figure 1 provides a good basis for describing the process of estimating change in carrying capacity due to harvesting activities. Under the existing conditions, 20 percent of the area is assumed to be in forage production, and the remaining 80 percent is classified as cover. Current carrying capacity is estimated at 116 animals, and is projected to stay constant if no harvesting is accomplished. This corresponds to the beginning point on each response curve in figure 1. The response curves then show average annual carrying capacity as a function of acres harvested for each series of harvest alternatives. The change in average annual carrying capacity reported for the alternatives in table 1 is the difference between these responses (for the appropriate level and type of harvest) and the annual carrying capacity of 116 animals for the no-action alternative.

ıble 1.—Alternatives for hypothetical timber sale

ternatives	Discounted total cost	Discounted agency cost	Discounted purchaser cost	Size of harvest	Timber harvest	Change in elk-carrying capacity
	Thousands of dollars			*Acres*	*M bd ft*	*Number of animals*
0	0	0.0	0.0	0.0	0.0	0.0
A2	200	35.7	164.3	166.7	1,417.0	− 9.8
A4	400	71.3	328.7	333.3	2,853.1	−17.0
A6	600	107.0	443.0	500.0	4,250.0	−24.3
A8	800	142.7	657.3	666.7	5,667.0	−31.8
A10	1,000	178.3	821.7	833.3	7,083.1	−37.6
A12	1,200	214.0	986.0	1,000.0	8,500.0	−41.2
A14	1,400	249.7	1,150.3	1,166.7	9,917.0	−45.6
A16	1,600	285.3	1,314.7	1,333.3	11,333.1	−49.1
A18	1,800	321.0	1,474.0	1,500.0	12,750.0	−52.8
B2	200	36.9	163.1	165.4	1,406.0	4.7
B4	400	72.6	327.4	332.1	2,822.7	9.2
B6	600	108.2	491.8	498.8	4,239.4	13.1
B8	800	143.9	656.1	665.4	5,656.0	15.5
B10	1,000	179.6	820.4	832.1	7,072.7	17.0
B12	1,200	215.2	984.8	998.8	8,489.4	17.6
B14	1,400	250.9	1,149.1	1,165.4	9,906.0	16.9
B16	1,600	286.6	1,313.4	1,332.1	11,322.7	15.2
B18	1,800	322.2	1,477.8	1,498.8	12,739.4	13.0
C2	200	33.9	166.1	151.5	1,288.0	8.8
C4	400	66.6	333.4	304.2	2,585.7	17.0
C6	600	99.3	500.7	456.9	3,883.4	24.2
C8	800	131.9	668.1	609.5	5,181.1	29.7
C10	1,000	164.6	835.4	762.2	6,478.8	32.9
C12	1,200	197.3	1,002.7	914.9	7,776.5	34.7
C14	1,400	230.0	1,170.0	1,067.0	9,074.2	34.8
C16	1,600	262.0	1,337.4	1,220.2	10,371.9	32.9
C18	1,800	295.3	1,504.7	1,372.9	11,669.7	29.2
D2	200	31.4	168.6	139.8	1,188.2	9.4
D4	400	61.5	338.5	280.6	2,385.4	18.0
D6	600	91.7	508.3	421.5	3,582.6	25.6
D8	800	121.8	678.2	562.3	4,779.8	32.0
D10	1,000	152.0	848.0	703.2	5,976.9	35.9
D12	1,200	182.1	1,017.4	844.0	7,174.1	38.3
D14	1,400	212.3	1,157.7	984.9	8,371.3	39.5
D16	1,600	242.4	1,357.6	1,125.7	9,568.5	38.6
D18	1,800	272.5	1,527.5	1,266.5	10,765.7	35.9
E2	200	28.1	171.9	124.1	1,054.5	9.3
E4	400	54.8	345.2	249.1	2,117.0	17.9
E6	600	81.6	518.4	374.1	3,179.5	25.6
E8	800	108.3	691.7	499.1	4,242.0	32.5
E10	1,000	135.1	864.9	624.1	5,304.5	37.6
E12	1,200	161.8	1,038.2	749.1	6,367.0	41.0
E14	1,400	188.6	1,211.4	874.1	7,429.5	42.9
E16	1,600	215.3	1,384.7	999.1	8,492.0	44.0
E18	1,800	242.1	1,557.9	1,124.1	9,554.5	42.9

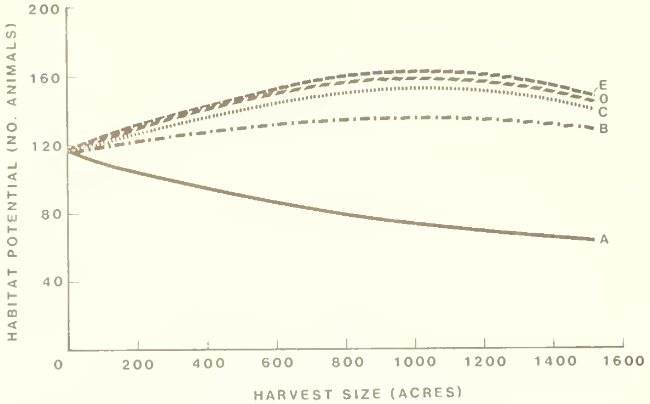


Figure 1.—Average annual elk habitat potential for the example area as a function of size of harvest, by series of alternatives A-E.

The responses in carrying capacity presented in figure 1 were based on the relationships presented in figure 2 (habitat effectiveness as a function of the percent of land in forage production), figure 3 (habitat effectiveness as a function of miles of road per section), and other information presented in a recent annual report on the Montana Cooperative Elk-Logging Study (Lyon and others 1982). These relationships were selected from many alternatives being evaluated in the study mentioned. A different selection of curves would produce somewhat different results.

In applying these relationships, the potential carrying capacity under ideal conditions (40 percent of area in forage production, 60 percent in cover, and no road effects) is estimated at 160 animals per year, which is fairly high but not unrealistic. The road effects shown in figure 3 were assumed to hold only when roads are left open to motorized use by the public. Roads closed to public vehicular traffic are thought to have no effect on habitat quality once harvesting activities are completed.

One final point should be made regarding the predicted output responses. The responses in carrying capacity illustrated in figure 1 exhibit decreasing marginal physical product. Along any given series of alternatives (with the exception of series A), as the size of harvest increases, carrying capacity increases but at a decreasing rate (that is, the slope is decreasing as scale of harvest gets larger). Slope stays positive out to a point (the maximum carrying capacity possible within each series), after which the carrying capacity decreases as size of harvest is further increased. The presence of decreasing marginal physical product is critical, for without it an optimal size of cut would not exist—more would always appear better.

Values

Timber is valued as mill-delivered logs at $140 per M bd ft. An explanation of the rationale for this basis (as opposed to valuing timber as standing trees) may be useful. Land managers can (and do) accomplish management objectives by the way roads and timber sales are

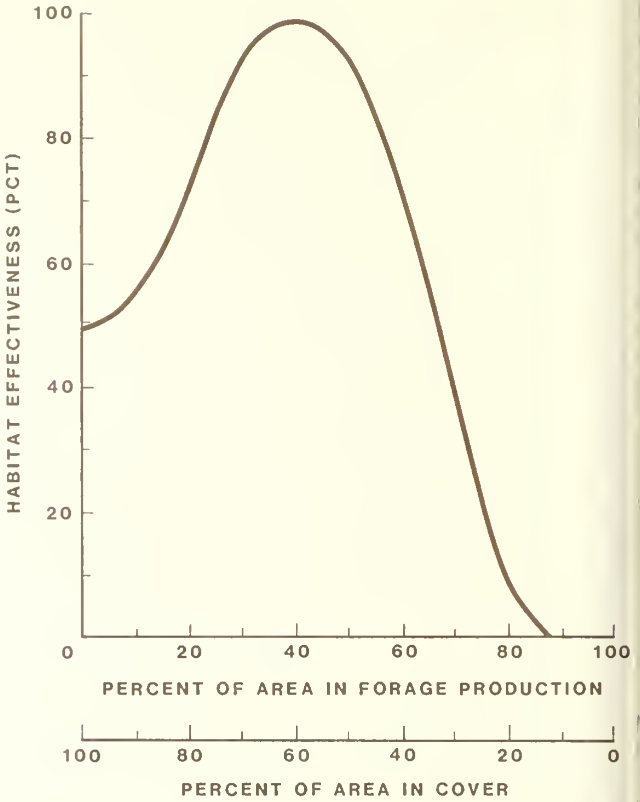


Figure 2.—Effectiveness of elk habitat as a function of percentage of area in cover and forage production (source: Lyon and others 1982).

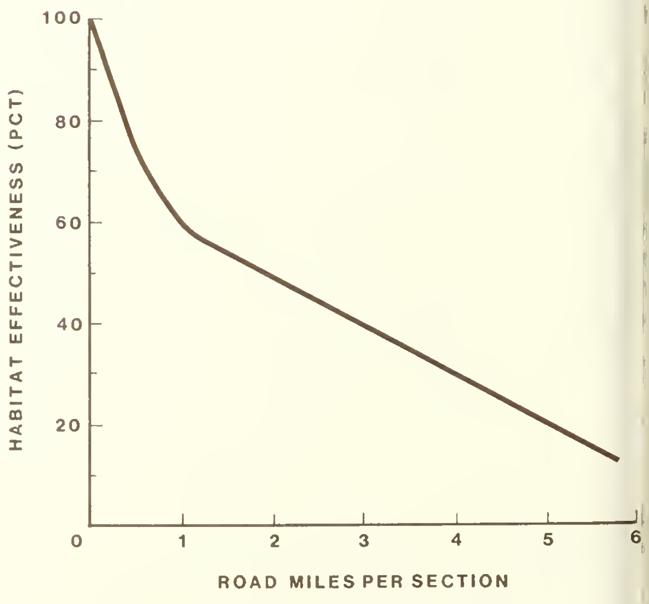


Figure 3.—The effect of road density on elk habitat (source: Lyon and others 1982).

esigned and by specifications included in timber sale ontracts. These things can affect stump-to-truck costs, aul costs, purchaser slash disposal costs, and other osts that must be paid by the purchaser of the timber, r a purchaser's subcontractor. Assuming competitive ıarkets, any $1 cost imposed on a purchaser (or a purhaser's subcontractor) can on the average be expected o result in $1 less the land manager receives for the imber sold. Thus, purchaser costs can be expected to ave the same effect on the seller of timber as a cost inurred directly by the seller. Valuing timber as delivered ɔgs allows purchaser costs to be identified explicitly as art of the "budget" available to the timber seller for onducting land management activities.

The value of the change in elk-carrying capacity was ased on the value of the recreational experience of elk unting. This implicitly assumes that the change in arrying capacity presented in table 1 (last column) orrectly measures the change in the number of animals ıat would be carried by the area. First, the value of an k living 1 year, V, was estimated as follows:

$$V = [\$/RVD] \times [RVD/Elk] \quad (1)$$

here:

$/RVD = $31.78, the RPA willingness to pay for a ecreation-visitor day (RVD) of elk hunting expressed in 982 dollars

RVD/Elk =the average number of elk hunting RVD's ıpported by an elk each year, estimated to be seven.

iven these numbers, V rounded to the nearest $10 quals $220.

The present value of the change in elk-carrying capacy over the next 30 years for the j[th] alternative, V_{oj}^{ELK}, ın be expressed in general terms as:

$$V_{oj}^{ELK} = \sum_{t=1}^{30} V_t \, Q_{jt} \, [\frac{1}{(1+i)^t}] \quad (2)$$

here:

V_t = the value of an elk in year t, expressed in conant dollars

Q_{jt} = the change in carrying capacity in year t for the alternative (last column in table 1)

i = the discount rate in real dollars.

his generalized form can be handled in the mathematiıl programming formulation, but must be simplified for ıe more restrictive graphic formulation. Let us assume o real price increase for V. Since Q_{jt} is constant over me in table 1 (change in carrying capacity is constant ver 30 years within each alternative), V_{oj}^{ELK} can be writn as:

$$V_{oj}^{ELK} = Q_j \, V_1 \sum_{t=1}^{N} [\frac{1}{(1+i)^t}]$$

$$V_{oj}^{ELK} = Q_j \, V_1 \, [\frac{(1+i)^t - 1}{i\,(1+i)^t}]$$

ecause V is constant across the j alternatives, it is conenient for the graphic formulation to set:

$$P = V\,[\frac{(1+i)^t - 1}{i\,(1+i)^t}]$$

sing a discount rate of 4 percent (in real dollar terms) ıd the previously calculated value of $220 for V, P equals $3,800 when rounded to the nearest hundred dollars. The present value of the change in carrying capacity, V_{oj}^{ELK}, can then be expressed in the familiar terms of price times quantity:

$$V_{oj}^{ELK} = 3{,}800 \bullet Q_j$$

Costs

Total cost for the alternatives in the second column of table 1 is in terms of change relative to no action. It has two major components. The first, Forest Service cost (third column), includes the sale-related costs that are paid with appropriated funds: sale preparation, sale administration, agency overhead, and road closure costs. The second cost component, purchaser-related costs (fourth column), include stump-to-truck, hauling, broadcast burning, and road construction and reconstruction. They represent the costs that must be covered by the value of the timber (when valued as delivered logs) for the sale to be financially viable. Given the objective of increased forage production for improved elk habitat, activities for regenerating the timber will not be undertaken. Thus regeneration costs were not included.

GRAPHIC APPROACH

The graphic formulation presented in figure 4 follows the logic of the continuous theoretical model. The first step in developing this formulation is to construct the iso-cost curves, which identify combinations of outputs that can be produced for given levels of cost. This is simply a matter of plotting the combinations of outputs predicted for each alternative presented in table 1. The iso-cost curve labeled 200 includes the alternatives with a total cost of $200,000, the curve labeled 400, the $400,000 alternatives, and so on. The order of the series (A-E) is illustrated on the curve labeled 600, and is the same on each iso-cost line. Technically, each iso-cost curve consists only of the points representing the alternatives, because linear combinations of projects have no logical interpretation. The points are connected here merely for convenience in identifying alternatives with common costs.

Next, benefits are entered in the form of iso-benefit lines, which arise from the simple price times quantity relationship. An iso-benefit line identifies combinations of outputs that have common total present value of benefits. To illustrate, an increase in carrying capacity of 35 animals (point W) would have a present value benefit of $133,000 (35 times the $3,800 discounted unit price identified earlier). Given the price of $140 per M bd ft, the same amount of benefit would be created by harvesting 950 M bd ft of timber (point T). Each combination of outputs lying on the line connecting points W and T has a total present value benefit of $133,000. An infinite number of iso-benefit curves could be drawn, each corresponding to a different level of total benefit. Nevertheless, location of one iso-benefit line establishes the entire family, because each has the same slope (slope equals the negative ratio of the output prices, with the price of the output on the ordinate as the denominator).

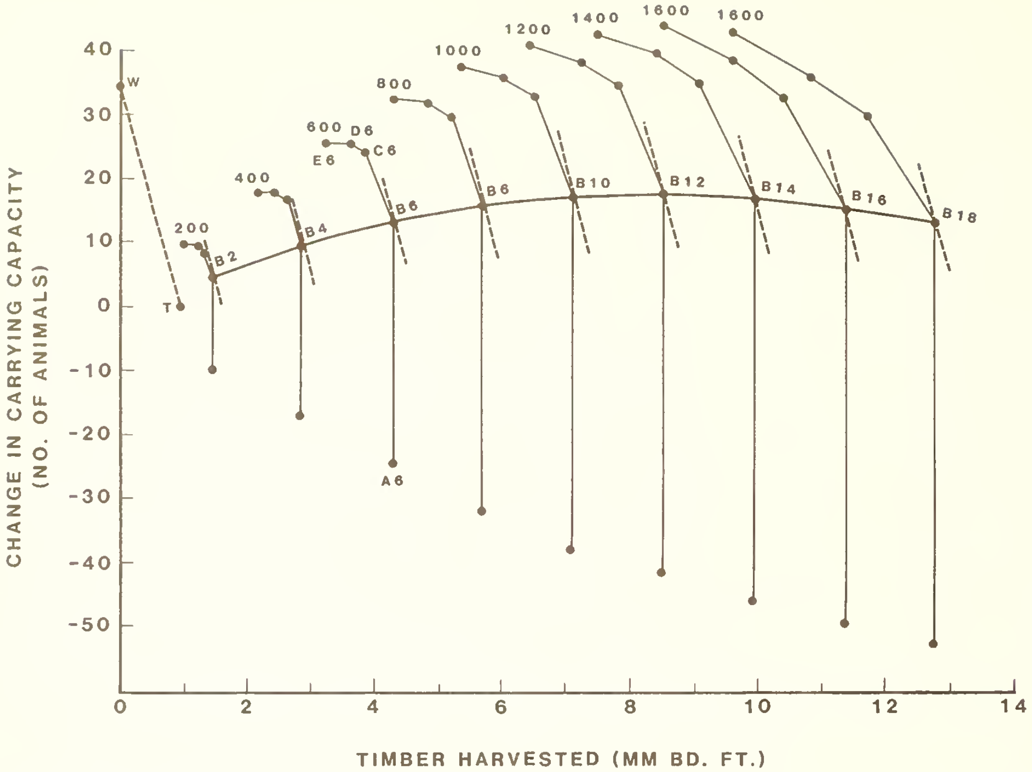


Figure 4.—Iso-cost curves, iso-benefit lines, and expansion path for timber sale example.

Solution

The graphic formulation is solved in two steps. First, the alternative with the highest present value is found for each iso-cost curve. For a given iso-cost curve this is the alternative that lies on the highest iso-benefit line. For iso-cost curve 600, this is alternative B6. There exists a comparable best point for each iso-cost curve. The locus of these points, the expansion path, identifies the best alternative for each budget level. In this example, the expansion path follows the alternatives in series B.

The next step is to identify which of the points along the expansion path maximizes present net value (PNV). This is most easily done by calculating PNV for each alternative on the expansion path, as illustrated in table 2. Alternative B12 is indicated as the best of the alternatives, having a PNV of $55,400. It would harvest about a thousand acres of timberland by means of 30- to 40-acre (12- to 16-ha) cutting units. About 8.5 million board feet of timber would be harvested, and habitat carrying capacity would be increased by an average annual amount of 17.6 elk over the 30 years following harvest.

Table 2.—Calculation of net benefit for alternatives lying on the expansion path

Alternatives	Timber harvest	Change in elk-carrying capacity	Discounted benefits[1]	Discounted cost	Present value
	M bd ft	*Number of animals*	*Thousands of dollars*		
B2	1,406.0	4.7	214.7	200	14.7
B4	2,822.7	9.2	430.2	400	30.2
B6	4,239.4	13.1	643.3	600	43.3
B8	5,656.0	15.5	850.7	800	50.7
B10	7,072.7	17.0	1,054.8	1,000	54.8
B12	8,489.4	17.6	1,255.4	1,200	55.4*
B14	9,906.0	16.9	1,451.0	1,400	51.0
B16	11,322.7	15.2	1,643.0	1,600	43.0
B18	12,739.4	13.0	1,832.9	1,800	32.9

[1]Calculated using per unit values of $140 per M bd ft for timber and $3,800 per animal-carrying capacity over 30 years.
*Identifies maximum net benefit.

ıntertemporal Analysis

The timber sale example contained only one inter-emporal output—the carrying capacity. It was handled ›y assuming output quantity is constant over time, and ›y expressing unit value as the present value of the con-tant annual quantity over 30 years. In reality, multiple-.se projects can be comprised of many intertemporal osts and outputs, all of which could vary in magnitude ver time. Expressing output as an annual average (as ı the timber sale example) may not always be accept-ble. Here we discuss several approaches for handling uch intertemporal problems graphically. It is suggested hat readers who lack a specific interest in techniques or integrating intertemporal analysis into the graphic pproach skip directly to the next subtopic, Discussion f Graphic Approach.

Formulating a graphic model in intertemporal terms equires expressing iso-cost and iso-benefit relationships o that the benefits and costs of the alternatives are ompared at a common point in time. Following custom, ve shall express these relationships in present-value erms.

Expressing iso-cost curves in present-value terms is traightforward. Simply discount the costs of all the esources used in a project to the present. Handling ıtertemporal output is somewhat more difficult. Both utput quantities and unit values can be changing over ime. Including these changes in graphic analyses is dif-cult for two reasons. First, the graphic approach re-uires that each output for an alternative be expressed s a single number. This number represents one dimen-ion on the base graph (example, in figure 4, carrying ca-acity was expressed on an average annual basis). Sec-nd, unit values must be expressed such that when ıultiplied by the single output response number, the roduct is in terms of discounted dollars.

There are several ways outputs and unit values can be xpressed to handle this problem, if either output or unit alue is constant over time. To explain, let us first re-rite equation 2 (the present value of elk-carrying capac-.y) in more general terms:

$$V_o = \sum_{t=1}^{n} P_t Q_t \left[\frac{1}{(1+i)^t}\right] \tag{3}$$

'here:

V_o = present value of the flow of output Q over n years

P_t = unit value of output in year t

Q_t = quantity of output in year t

i = discount rate.

The first approach requires that unit value be constant ver time. If P represents a constant unit value, it can e factored out of the summation:

$$V_o = P \sum_{t=1}^{n} Q_k \left[\frac{1}{(1+i)^t}\right] \tag{4}$$

ı this formulation, output is expressed as a single num-er by the term:

$$Q_o = \sum_{t=1}^{n} Q_t \left[\frac{1}{(1+i)^t}\right] \tag{5}$$

so-cost curves would then be expressed in terms of Q_o per discounted cost. Unit value used in computing iso-benefit is simply P, the stated value of a unit of Q.

A potential disadvantage of formulating output in this manner is that people may have difficulty relating to quantity expressed as Q_o. It may be easier for some to relate to quantity if it were expressed in terms of an annual equivalent output, Q^A. This can be accomplished as follows:

$$Q^A = Q_o \left[\frac{i(1+i)^n}{(1+i)^n - 1}\right] \tag{6}$$

To maintain the correct calculation for V_o, unit value must be multiplied by the inverse of the factor multipled by Q_o:

$$P_o = P \left[\frac{(1+i)^n - 1}{i(1+i)^n}\right] \tag{7}$$

Present value of the flow of output can then be written as:

$$V_o = P_o \bullet Q^A \tag{8}$$

Here, unit value (P_o) is the present value of a series of annual outputs. The single value for output, Q^A, is an annual flow equivalent of the actual output flow.

Q^A differs from an "ordinary annual average." The product of Q^A times P_o is equivalent to the present value that would be calculated by discounting each year's benefit (quantity times price in each year) separately and summing. This equality does not hold if annual output is computed as a simple arithmetic average unless, of course, annual output quantity actually is constant.

Both approaches discussed thus far require a constant unit value over time. It is possible to allow unit value to vary over time if the annual quantity of output is constant over time. If Q represents a constant annual flow, it can be factored out of the summation in equation 3:

$$V_o = Q \sum_{t=1}^{n} P_t \left[\frac{1}{(1+i)^t}\right] \tag{9}$$

In this formulation, unit value is expressed as:

$$P_o = \sum_{t=1}^{n} P_t \left[\frac{1}{(1+i)^t}\right] \tag{10}$$

This differs from equation 7 in that P_t is allowed to vary here. Output is expressed in the iso-cost curves as a constant annual quantity occurring over n years.

The reader should note that none of these approaches allow both unit value and output to vary over time. In fact, it does not appear possible to allow for this occurrence using the graphical approach. The order of multiplication and summation indicated in equation 3 must be maintained if both P_k and Q_k vary over time ($\Sigma[P_k \bullet Q_k] \neq \Sigma P_k \bullet \Sigma Q_k$). Only when one of these variables was held constant was it possible to factor them out of the summation to develop the approaches presented.

Discussion of Graphic Approach

The graphic approach rather clearly depicts the nature of economic efficiency in multiple-use production. Consider figure 4. Each iso-cost curve shows the opportunity cost of producing increased amounts of one output at

the expense of the other. The specific production points (output combinations) comprising each iso-cost curve are readily available for inspection and verification. The expansion path shows optimal solutions associated with various scales of activity. Finally, sensitivity analyses can be performed graphically to determine the change in relative prices needed to change the preferred alternative on an iso-cost curve. This is done by rotating the iso-benefit line and observing the slope required to identify a new preferred alternative (recall slope of the iso-benefit line equals the inverse ratio of the unit values). The need to more accurately estimate unit values can thereby be assessed.

The graphic approach, however, is inherently limited. Perhaps the most significant limitation is that the number of outputs that can be handled effectively is limited to two. Second, intertemporal analysis imposes restrictions as discussed in the previous section. Third, sensitivity analyses regarding the effect of changes in costs or output quantities can only be conducted by recalculating the iso-cost relationships.

MIP APPROACH

The discrete joint production model presented graphically can also be formulated as a mixed-integer programming (MIP) problem. This approach alleviates the limitations of the graphic formulation discussed in the previous section. It can handle more than two joint outputs. Second, multiple time periods can be handled more easily than in the graphic approach. Third, the MIP formulation provides useful capability for identifying how sensitive the choice of the preferred alternative is to underlying assumptions and projections. Finally, it lends itself to automation. Software could be written such that all the user has to do is enter the data. The computer would take the data, generate the appropriate matrix, and calculate the solution.

The General Model

MIP is a special case of linear programming. Like linear programming, it has decision variables (columns in the matrix), linear constraint rows, and a linear objective function. The major difference is that some of the decision variables are restricted to integer values of either 0 or 1 in the MIP formulation. This provides the ability to express decision variables as whole projects. If in a solution a 0,1 integer variable equals 1, the project represented by that variable was chosen to be accomplished. A value of 0 for project variables indicates those projects were not selected. (Readers interested in a more thorough discussion of MIP are referred to Hillier and Lieberman [1974] or Plane and McMillan [1971].)

The MIP formulation proposed is:

$$\text{Maximize PNV} = \sum_{i=1}^{L} -TC_i X_i + \sum_{j=1}^{M}\sum_{t=1}^{N} DP_{jt} V_{jt} + \sum_{j=1}^{M}\sum_{t=1}^{N} - DP_{jt} W_{jt} \qquad (11)$$

subject to:

$$\sum_{i=1}^{L} X_i \leq 1 \qquad (12)$$

$$\sum_{i=1}^{L} Y^{+}_{ijt} X_i - V_{jt} = 0 \text{ (for all } V_{jt}) \qquad (13)$$

$$\sum_{i=1}^{L} Y_{ijt} X_i + W_{jt} = 0 \text{ (for all } W_{jt}) \qquad (14)$$

$$\text{all } X_i = 0 \text{ or } 1 \qquad (15)$$

THE VARIABLES

There are three sets of variables in this formulation—X_i's, V_{jt}'s, and W_{jt}'s. The X_i's are the project alternatives. Each X_i represents a whole project, and is restricted to the values of either 0 or 1 as indicated by equation 15. The coefficients for the X_i variables are expressed on a project basis (example, TC_i represents total cost for project X_i).

The variables labeled V_{jt} store the positive quantity of the j^{th} output in time period t expected from the alternatives. Unlike the X_i's these are continuous variables that can assume any nonnegative value.

The final set of variables, W_{jt}, measure negative quantity of the j^{th} output in time period t expected from the alternatives. This situation can arise when output is defined as change in volume relative to the no-action alternative (as in the example in table 1). These variables are necessary to avoid infeasibilities that would occur if a V_{jt} variable were to be set equal to a negative output volume (algorithms generally require all variables be nonnegative). Instead, W_{jt} measures the absolute value of the negative volume, and the negative sign is attached to its objective function coefficient ($-DP_{jt}$). A W_{jt} variable is needed only when there is a negative volume predicted for one or more projects for the j^{th} output in time period t. Thus, there should be only a few W_{jt} variables in most applications.

THE ROWS

Equations 11-14 represent the rows in the MIP model. Equation 15 is a restriction placed on the model, but does not appear as a row in the matrix. The objective function to be maximized is PNV (equation 11). The coefficients for the X_i variables, $-TC_j$, are the discounted total costs for the X_i projects. These costs are preceded by a negative sign, because this row measures PNV. The output variable coefficients, DP_{jt} and $-DP_{jt}$ are the unit values for output j in time period t, discounted to present value terms. As explained earlier, W_{jt} variables measure decreases in outputs and therefore have negative unit value coefficients.

The first constraint (equation 12) specifies that not more than one project can be chosen. (Because the X_i's are restricted to values of 0 or 1, combinations of parts of projects that sum to 1.0 are not permitted.) The less-than-or-equal-to form of this constraint does, however, permit a solution in which none of the project alternatives are chosen—the no-action alternative. This would occur if the PNV for each alternative is negative. The model can be forced to choose a project alternative other than the no-action alternative by reformulating this row to equal 1.0.

Equation 13 actually represents a set of rows whose function is to "transfer" positive output quantities fro

the resource project in solution (X_i) to the variables measuring output volume (V_{jt}). There is one of these rows for each combination of output and time period (i.e., for each V_{jt}). The Y^t_{ijt} coefficients in these rows measure the positive quantity of the j^{th} output produced by project X_i in time period t.

Equation 14 represents the set of rows that "transfer" negative output quantities from the project in solution to the variables measuring negative volume (W_{jt}). The Y_{ijt} coefficients in these rows measure the negative quantity of the j^{th} output produced by project X_i in time period t. There is one such row needed for each W_{jt} present, which (as explained earlier) should only be a few in most applications.

WHY THIS FORMULATION?

Thoughtful readers may be wondering at this point why output values are not simply included in the objective function coefficients for the project variables. This would alleviate the need for the output variables V_{jt} and W_{jt} and for equations 13 and 14. The reason is that handling output as separate variables provides advantages for conducting sensitivity analyses on unit values and output quantities.

To illustrate, assume output value has been included in the objective function coefficients for the project variables in a model. The analyst now wants to determine what effect a unit value change would have on a previously obtained optimal solution. The shadow prices from this previous solution are not useful for this purpose. Shadow price measures how much the objective function coefficient for a project variable would have to increase for that variable to become part of the optimal solution, assuming all other coefficients remain unchanged. Other objective function coefficients, however, would change as a result of a unit value change as long as those projects are also producing the same product.

The most straightforward way to determine the effect of a unit value change is to implement that change in the original model and resolve. This, however, would require recalculating and changing every one of the objective function coefficients. In contrast, the equations 11-15 formulation would require changing only the objective function coefficient(s) for that output (one coefficient for each time period t that V_{jt} is quantified), prior to resolving the model. Similar advantages exist in applying some of the other postoptimization techniques for conducting sensitivity analyses that will be discussed later.

Solving The MIP Formulation

There are several options for solving the formulation presented by equations 11-15. One option would be to use algorithms specifically designed for solving MIP problems, such as the branch and bound technique. These algorithms have several disadvantages. First, the capabilities for conducting sensitivity analyses are limited. They do not, for example, offer the majority of the postoptimality techniques available in continuous linear programming software. Second, they are rather restrictive in terms of the size of model (number of rows and columns) that can be handled efficiently. This, however, does not appear to be a significant problem for the class of programming problem created by the equations 11-15 formulation. Third, computer software for solving MIP problems is not as readily available as, say, software for solving continuous linear programming problems, particularly for small computers.

Another option for solving this MIP formulation is to use a conventional continuous linear programming algorithm. This involves simply treating equations 11-14 in the general model as a continuous linear programming problem. If no additional constraint types are added to this equation 11-14 formulation (several will be discussed later), the optimal continuous solution will be the optimal MIP solution.

An explanation might be helpful at this point. Equations 13 and 14 merely ensure that the output variables (V_{jt} and W_{jt}) equal the correct quantity. The key constraint is equation 12. Linear programming algorithms will maximize the PNV objective function by entering as much of the most profitable project as possible. When the upper limit of the equation 12 constraint is reached, the most profitable project variable will equal 1.0. All other project variables (the X_i's) will equal zero at this point. This is an integer solution. Furthermore, it is the optimal solution, because adding any other project to the solution would require the amount of the most profitable project to be reduced to continue to satisfy equation 12. Any such change would reduce the value of the objective function.

Use of continuous linear programming algorithms to solve this MIP formulation provides several advantages. Most importantly, it makes the standard linear programming postoptimization techniques available for conducting sensitivity analyses. Secondly, it makes using a small computer for solving this type of problem more viable, because software for solving continuous linear programming problems is more readily available than MIP software.

The disadvantage of the continuous linear programming approach is that it may not yield integer solutions if additional constraints are added to the equations 11-15 model, an option that will be discussed later. In instances when continuous algorithms do not yield integer solutions, optimal integer solutions would be most easily found using an MIP algorithm.

The Timber Sale Example

The timber sale example presented earlier was formulated as an MIP problem to illustrate how the generalized model can be applied in practice. The following discussion covers the formulation and solution of this model.

FORMULATION

The MIP formulation for the timber sale example is presented in table 3. The project alternatives (the X_i's in equations 11-15) are the alternatives A2 through E18 listed in table 1. Two positive output variables (V_{jt} in equations 11-15) are present. They are TIMB and WILD, which respectively measure positive quantities of timber

Table 3.—Formulation of the timber sale example as an MIP problem[1]

Row name	A2	A4 ...	E18	TIMB	WILD	NWILD	RHS
PNV	-200.0	-400.0 ...	-1,800.0	0.140	3.8	-3.8	
EQN 12	1.0	1.0 ...	1.0				≤1.0
TVOL	1,417.0	2,833.1 ...	9,554.5	-1.0			=0.0
WVOL			42.9		-1.0		=0.0
NWVOL	-9.8	-17.0				-1.0	=0.0

[1]Variables A2 through E18 are treated as 0, 1 integer variables.

and change in elk-carrying capacity. Negative change in elk-carrying capacity (corresponding to W_{jt} in equations 11-15) is measured by NWILD.

The objective function to be maximized is the row labeled PNV, which measures present net value in thousands of dollars. The coefficients for the project alternatives are the discounted total costs from the second column in table 1. The objective function coefficients for TIMB and WILD are the unit values for these outputs developed earlier. Finally, the coefficient for NWILD is the negative unit value for elk-carrying capacity, since NWILD measures decrease in carrying capacity.

The first constraint shown is row EQN 12, which corresponds to equation 12 in the general formulation. The coefficient for each of the project variables is 1.0, and the row is set less-than-or-equal-to 1.0. This specifies that no more than one project can be chosen, but allows for the possibility of not choosing any of the project alternatives—the no-action alternative. (Recall, outputs and costs for the projects are expressed in terms of change from the no-action alternative.)

The next row is TVOL, which corresponds to equation 13 in the general model. It sets the variable TIMB equal to the positive quantity of timber expected from the project alternative selected. The coefficients for the project alternatives predict total timber yield for each alternative and come from the sixth column in table 1.

Row WVOL sets the variable WILD equal to the positive change in elk-carrying capacity in the same manner as TVOL "transfers" timber quantity to TIMB. The project alternative coefficients measure the positive change in carrying capacity and come from the last column in table 1. No coefficients exist in this row for project alternatives A2 through A18 (note, this is equivalent to a coefficient of zero) because the change in carrying capacity is negative for these alternatives.

Row NWVOL corresponds to equation 14 of the general model, and sets NWILD equal to the project coefficients measuring decrease in elk-carrying capacity. These coefficients also come from the last column in table 1. No coefficients are present in this row for alternatives B2 through E18 because these projects are expected to result in an increase in elk-carrying capacity.

THE SOLUTION

The timber sale example in table 3 was solved using the continuous linear programming option in the Functional Mathematical Programming System (FMPS) available at the USDA Fort Collins Computer Center. The solution is presented in figure 5. Although the format used in this figure is specific to FMPS, the information presented is standard among mathematical programming packages.

The first item of interest is the value of the objective function, row PNV. It is found in the portion labeled SECTION 1 - ROWS under the column headed ACTIVITY. The value identified here (55.396) deviates slightly from the value of the selected alternative identified in table 2, due to rounding.

Next, examine the second portion of the solution output labeled SECTION 2 - COLUMNS. The values for the decision variables in the optimal solution are presented in the column headed ACTIVITY. Glancing down this column, one sees that project B12 equals 1.0. This means B12 was the alternative selected—the same project selected earlier in table 2. The other project variables equal zero (represented by a decimal) identifying that they were not chosen in the solution process.

The outputs predicted for the selected alternative B12 are the entries in the activity column for the output variables. TIMB equals 8,489.4 M bd ft, WILD equals an increase of 17.6 animals in carrying capacity, and NWILD equals zero, because change in carrying capacity is predicted to increase rather than decrease.

Sensitivity Analyses

Output responses, costs, and unit values included in such a model are predicted future outcomes, and thus are not known with certainty. Sensitivity analysis can aid the analyst in dealing with uncertainty. It can help determine the range of predicted outcomes over which an alternative identified as optimal remains optimal. Secondly, it can be used to identify what other alternatives are preferred when predicted outcomes are outside the limits for which a given alternative is optimal.

Unfortunately, most of the postoptimization techniques used in linear programming for sensitivity analyses are not available in the branch and bound MIP algorithm commonly used in MIP computer packages. If branch and bound algorithms are used, sensitivity analysis is limited to changing the parameter(s) of interest and resolving. If integer solutions can be obtained with standard linear programming algorithms, however, then some of the more sophisticated postoptimal techniques for conducting sensitivity analyses could be useful. Here we discuss changing parameters and resolving, and several postoptimization techniques available in linear programming that appear particularly useful in the formulation presented by equations 11-15.

SECTION 1 - ROWS PRIMAL-DUAL OUTPUT

NUMBER	..NAME..	AT	..ACTIVITY..	SLACK ACTIVITY	.LOWER LIMIT	.UPPER LIMIT	DUAL ACTIVITY	.INPUT COST.	REDUCED COST
1	PNV	FR	55.396000	-55.396000	NONE	NONE	-1.000000	.	-1.000000
2	EQN 12	EQ	1.000000	.	1.000000	1.000000	55.396000	.	55.396000
3	TVOL	EQ	.	.	.	.	-.140000	.	-.140000
4	WVOL	EQ	.	.	.	.	-3.800000	.	-3.800000
5	NWVOL	EQ	.	.	.	.	-3.800000	.	-3.800000
6	APV	FR	203.716000	-203.716000	NONE	NONE	.	.	.
7	FSCOST	FR	215.199999	-215.199999	NONE	NONE	.	.	.

SECTION 2 - COLUMNS PRIMAL-DUAL OUTPUT

NUMBER	..NAME..	AT	..ACTIVITY..	.INPUT COST.	.LOWER LIMIT	.UPPER LIMIT	REDUCED COST
8	A2	LL	.	-200.000000	.	NONE	94.256000
9	A4	LL	.	-400.000000	.	NONE	123.362000
10	A6	LL	.	-600.000000	.	NONE	152.735998
11	A8	LL	.	-800.000000	.	NONE	182.855999
12	A10	LL	.	-1000.000000	.	NONE	206.641998
13	A12	LL	.	-1200.000000	.	NONE	221.955999
14	A14	LL	.	-1400.000000	.	NONE	240.296000
15	A16	LL	.	-1600.000000	.	NONE	255.341999
16	A18	LL	.	-1800.000000	.	NONE	271.035999
17	B2	LL	.	-200.000000	.	NONE	40.696000
18	B4	LL	.	-400.000000	.	NONE	25.258000
19	B6	LL	.	-600.000000	.	NONE	12.100000
20	B8	LL	.	-800.000000	.	NONE	4.656000
21	B10	LL	.	-1000.000000	.	NONE	.618000
22	B12	BS	1.000000	-1200.000000	.	NONE	.
23	B14	LL	.	-1400.000000	.	NONE	4.336000
24	B16	LL	.	-1600.000000	.	NONE	12.458000
25	B18	LL	.	-1800.000000	.	NONE	22.480000
26	C2	LL	.	-200.000000	.	NONE	41.636000
27	C4	LL	.	-400.000000	.	NONE	28.798000
28	C6	LL	.	-600.000000	.	NONE	19.760000
29	C8	LL	.	-800.000000	.	NONE	17.182000
30	C10	LL	.	-1000.000000	.	NONE	23.344000
31	C12	LL	.	-1200.000000	.	NONE	34.826000
32	C14	LL	.	-1400.000000	.	NONE	52.768000
33	C16	LL	.	-1600.000000	.	NONE	78.309999
34	C18	LL	.	-1800.000000	.	NONE	110.677999
35	D2	LL	.	-200.000000	.	NONE	53.328000
36	D4	LL	.	-400.000000	.	NONE	53.040000
37	D6	LL	.	-600.000000	.	NONE	56.552000
38	D8	LL	.	-800.000000	.	NONE	64.624000
39	D10	LL	.	-1000.000000	.	NONE	82.209999
40	D12	LL	.	-1200.000000	.	NONE	105.481999
41	D14	LL	.	-1400.000000	.	NONE	133.313999
42	D16	LL	.	-1600.000000	.	NONE	169.125999
43	D18	LL	.	-1800.000000	.	NONE	211.778000
44	E2	LL	.	-200.000000	.	NONE	72.426000
45	E4	LL	.	-400.000000	.	NONE	90.995999
46	E6	LL	.	-600.000000	.	NONE	112.985999
47	E8	LL	.	-800.000000	.	NONE	138.015999
48	E10	LL	.	-1000.000000	.	NONE	169.886000
49	E12	LL	.	-1200.000000	.	NONE	208.216000
50	E14	LL	.	-1400.000000	.	NONE	252.245998
51	E16	LL	.	-1600.000000	.	NONE	299.315998
52	E18	LL	.	-1800.000000	.	NONE	354.745998
53	TIMB	BS	8489.399902	.140000	.	NONE	.
54	WILD	BS	17.600000	3.800000	.	NONE	.
55	NWILD	BS	.	-3.800000	.	NONE	.

Figure 5.—Solution to MIP formulation of timber sale example.

Table 4.—The unit values over which project B12 remains optimal

Outputs	Lowest value	Highest value	Project selected if unit value is below the identified lowest value	Project selected if unit value is above the identified highest value
	Dollars			
WILD	2,770.00	5,220.00	B10	C8
TIMB	139.56	143.06	B10	B14

UNIT VALUES

Several types of sensitivity analyses for unit values are potentially useful. The choice depends on the question being asked. The effect of some specific change in unit value on a previously optimal solution is best determined by making that change in the formulation and resolving. This is accomplished by changing the objective function coefficient for the output variables associated with the change in unit value. This can be done easily with a text editor because only a few numbers would change. The model is then resolved using standard procedures. No knowledge of the more sophisticated postoptimization procedures is needed.

Analysts may also be interested in determining the range in unit values over which a particular solution remains optimal. This could be calculated by systematically changing unit values and resolving, but this process would likely require a large number of solutions. An easier approach would be to use a postoptimization technique available in most linear programming packages which calculates this directly. To illustrate, the EXRANGE procedure in FMPS was used to calculate the range in unit values over which the figure 5 solution remains optimal. The results are summarized in table 4. The lowest and highest unit values for WILD are, respectively, $2,770 and $5,220. As long as the unit value for WILD is within this range, project B12 is preferred, assuming other parameters constant.

In addition to the range in unit values, linear programming ranging procedures can be expected to identify what project would be preferred if the unit value falls below or rises above the indicated range (see the last two columns of table 4). For example, if the unit value for WILD were to fall below $2,770, then project B10 would be preferred. This does not imply that B10 is preferred for all unit values less than $2,770, but rather for some range, whose lower unit is unspecified and whose upper limit is $2,770.

If the question to be asked is how does the preferred project change over a wide range in unit values, then parametric programming can be used to good advantage. Parametric programming involves reformulating the objective function from:

$$Z = \sum_{j=1}^{N} C_j X_j \tag{16}$$

a general expression for equation 11, to:

$$Z(\theta) = \sum_{j=1}^{N} (C_j + \alpha_j \theta) X_j \tag{17}$$

Here, α_j represents constant changes to be applied to the objective function coefficients (C_j). The symbol θ represents a scalar that, when multiplied times the α_j values, results in proportional change in the objective function coefficients. In the parametric programming procedure, θ is incremented upward, starting at zero (where equations 16 and 17 are equivalent) to some user specified upper limit. In this process, the values for θ, where the optimal solution changes, are identified.

To illustrate the use of parametric programming, assume we desire to investigate how the preferred alternatives change over the range of timber prices from $120 per M bd ft to $200 per M bd ft, all else remaining equal. The changes that would be made to the matrix presented in table 3 are as follows: First, change the objective function coefficient for TIMB from 0.140 to 0.120 ($120 expressed in thousands). Next, a row corresponding to α_j in equation 17 must be added to the matrix. Because the objective function coefficient for TIMB is the only coefficient to be changed in this analysis, the only nonzero coefficient in this new α_j row would be the coefficient for TIMB. Set this coefficient equal to 0.120. The scalar θ then measures the percentage of change (decimal form) from the starting price of $120 per M bd ft.

The results from this parametric programming analysis are summarized in table 5. Project C2 is optimal over the range in timber prices from $120 to $129.33 per M bd ft. As timber price was increased from $129.33 per M bd ft, the optimal solution moves out series B of project alternatives. The selection of the scale of project within series B is shown to be sensitive to timber price. However, the type of harvesting in series B is clearly preferred over the approach in the other series of alternatives over the range in timber prices.

Table 5.—Preferred alternatives and the range in timber prices over which they are optimal[1]

Project alternative	Range in timber price over which project is optimal
	Dollars per M bd ft
C2	120.00 – 129.33
B4	129.33 – 130.71
B6	130.71 – 134.74
B8	134.74 – 137.15
B10	137.15 – 139.56
B12	139.56 – 143.06
B14	143.06 – 145.73
B16	145.73 – 147.07
B18	147.07 – 200.00

[1]All other parameters held constant at the levels in table 1.

UTPUTS

In the model formulation depicted by equations 11-15, is typical for an output to be produced (at least at ›me level) by most, if not all, projects. It would seem ıat the question most frequently asked regarding out- ıts would be how much effect would systematically un- ›restimating or overestimating outputs across the ›ojects have on the preferred alternative. If such a sys- ›matic change can be expressed as a percentage of ıange from the previously predicted outputs, inves- gating this effect is relatively easy. The suggested ap- ›oach would be to modify the coefficient(s) for the out- ıt variable(s) in the output rows (equations 13 and 14) ıd resolve the model.

This process is best explained via an example. Assume 'e desire to determine if a 10 percent increase in elk- ırrying capacity over that already predicted would af- ct which project is chosen. This 10 percent increase 'ould be approximated by changing the coefficient for 'ILD in row WVOL (table 3) from −1.0 to −0.9. This) percent decrease in the coefficient requires a 10 per- ›nt larger quantity allocated to WILD to maintain the ıuality of row WVOL. The model would then be re- ›lved to determine the effect of the change.

In this instance, the 10 percent increase in change in k-carrying capacity had no effect on the project chosen ›12). The only effect was the value of the objective nction increased to $62,800.

OST

Change in virtually any underlying cost (examples, bor costs or equipment costs) would change the objec- ›e function coefficient for each project alternative. ıerefore, for reasons discussed earlier, shadow prices ›ovide little information regarding how cost changes ight affect an optimal solution. The effect of potential ıanges in costs is best analyzed using parametric ogramming procedures.

The general formulation for parametric programming ›scribed by equation 17 also applies here. The only fference is that here the α_j row to be added to the odel should be comprised of the cost changes to be ap- ied to the objective function. We suggest that the α_j w be comprised of the costs included in the objective nction coefficients for the resource(s) for which the ef- ct(s) of cost changes is (are) to be investigated. To in- stigate cost increases, these α_j coefficients should be gative. For example, if the effect of increasing fuel st is to be measured, α_j would be comprised of the eviously calculated total fuel cost for each project. ven this definition for α_j, θ measures the percent ange (decimal form) in these costs. The effect of in- ›ases in costs is then analyzed when the parametric ogramming procedure increments θ upwards, starting zero. The results identify values for θ where the op- nal solutions change.

The effect of decreases in cost can be investigated by anging the signs on the coefficients in the α_j row from gative to positive. When formulated in this manner, as s incremented upward from zero, the product of θ and is added (rather than subtracted) giving the effect of creasing costs.

To illustrate this approach, parametric programming was used to analyze the effects of changes in purchaser-related costs. The coefficients for the α_j row (which were added to the model presented in table 3) were the purchaser costs presented in the fourth column of table 1. The signs of these coefficients were negative for the portion of the analysis dealing with cost increases and positive for the portion dealing with cost decreases. Changes from a 30 percent decrease to a 30 percent increase were investigated.

The results are summarized in table 6. Project B12 remains optimal as long as purchaser cost does not decrease more than 2.6 percent or increase more than 0.3 percent. As purchaser cost increases from the original amount, smaller scale series B alternatives are preferred. Decreases in purchaser cost result in larger scale series B alternatives being preferred. The preferred scale within series B is shown to be quite sensitive to changes in purchaser cost. But this analysis indicates the series B method of harvesting is preferred over the other approaches over quite a large range in purchaser cost.

Table 6.—Preferred alternatives and the range in changes in purchaser costs over which they are optimal[1]

Project alternative	Range in purchaser costs over which project is optimal		
	Percent change[2]		
B18	30.0 (decrease)	–	6.1 (decrease)
B16	6.1 (decrease)	–	4.9 (decrease)
B14	4.9 (decrease)	–	2.6 (decrease)
B12	2.6 (decrease)	–	0.3 (increase)
B10	0.3 (increase)	–	2.4 (increase)
B8	2.4 (increase)	–	4.5 (increase)
B6	4.5 (increase)	–	8.0 (increase)
B4	8.0 (increase)		9.4 (increase)
B2	9.4 (increase)	–	30.0 (increase)

[1]All other parameters held constant at the levels in table 1
[2]Percentage of change from the purchaser costs in table 1.

Other Constraints

In actual planning situations there may be management desires that are best handled as constraints. For example, it may be useful to constrain the model to choose an alternative that has a positive appraised sale value or a sediment impact less than some maximum acceptable level. Such constraints could easily be added to the equations 11-15 formulation. The general form for such constraints is as follows:

$$\sum_{i=1}^{L} a_{kit} X_i \gtreqless B_{kt} \qquad (18)$$

Here, X_i represents the project alternatives (as before). The coefficients a_{kit} measure the quantity of k (any cost or physical quantity; for example, sediment, water) associated with project X_i in time t. B_{kt} represents the upper and/or lower limits placed on k in time t.

Equation 18 would be modified to the following form for establishing a minimum appraised sale value:

$$\sum_{i=1}^{L} (-PC_{it} X_i) + \sum_{j=1}^{N} P_{jt} V_{jt} \geq B_t \qquad (19)$$

where V_{jt} measures output quantity of timber in category j in time t. The coefficients for X_i, $-PC_{it}$, are the costs (undiscounted) that must be covered by the value of timber in time t. P_{jt} is the undiscounted unit price for timber in category j in time t. B_t represents the lower limit for sale value specified by the user. There could be a row of this type for each time period there is a potential sale.

Equations 18 and 19 could also be included as "free" or unconstraining rows, which are allowed by most linear programming packages. Such rows do not influence the solution, but the total value of the row is calculated in the solution process. Free rows are useful for monitoring appraised values, costs, and so on.

DISCUSSION

Comparing to Other Linear Programming Formulations

Linear programming formulations common in forestry (FORPLAN, Gilbert and others 1982; Timber RAM, Navon 1971; Resource Allocation Analysis, USDA Forest Service 1975) involve delineating the area being modeled into units, within which the acres are homogenous with regard to one or more characteristics (for example, timber productivity). The decision variables are management prescription alternatives, which are developed for each unit. These prescription alternatives are expressed on a per-acre basis, that is, $X_{ij} = 1$ means 1 acre of prescription j on unit i. All output and input coefficients are therefore on a per-acre basis.

In contrast, the decision variables in the equations 11-15 MIP formulation represent whole alternatives that apply to the entire area. These alternatives are restricted to values of 1 (do project) or 0 (not do project). Differences in the scale of some particular type of activity (scale of a particular type of harvest in the example) are represented by additional decision alternatives.

These differences in structure result in differences in the nature of analyses provided. One difference is that diminishing marginal productivity cannot be modeled in the ordinary linear programming formulation in the same sense as it can in the MIP formulation and the theoretical continuous joint production model. To illustrate the difference, consider modeling the alternatives in the previous example using ordinary linear programming. For simplicity, assume the 4,000-acre (1 619-ha) area is homogeneous, alleviating the need for delineating units. We shall define five prescription alternatives, one for each harvest series. One unit of each variable represents 1 acre (0.4 ha) of harvest activity. We must next formulate a constraint that places an upper limit on the number of acres that can be harvested. Set this upper limit at 1,600 acres (647 ha).

Under this formulation the elk-carrying capacity response to acres harvested is linear—if 1 acre of harvest generates an increase in carrying capacity of Y, 2 acres generate 2Y, etc. No diminishing marginal product is present as was the case in figure 1. The result is that each solution (maximizing PNV) will allocate 1,600 acres (647 ha) to harvest, as long as at least one of the alternatives has a positive PNV per acre. That is, acres are allocated until the upper limit of 1,600 acres (647 ha) of harvest is reached. The only way to obtain a solution with a different level of harvest is to change this upper limit. This formulation is unable to analyze economic efficiency related to scale of harvest as was done by the MIP formulation (recall the various levels of harvest identified as best in tables 4, 5, and 6).

The second difference is in the level of site specificity. The spatial arrangement of activities that comprise a project can be identified in the MIP formulation. In contrast, spatial location is not part of the definition of decision variables in ordinary linear programming formulations. A management prescription simply must be applied somewhere within the homogeneous unit for which it was developed.

This difference is important because spatial arrangement can affect input and output relationships. For example, road cost is usually entered as an average per-acre cost in ordinary linear programming formulations. In reality, however, the road cost associated with implementing an acre of some specific prescription is highly variable, depending on where it occurs. These relationships are handled more precisely in the MIP formulation.

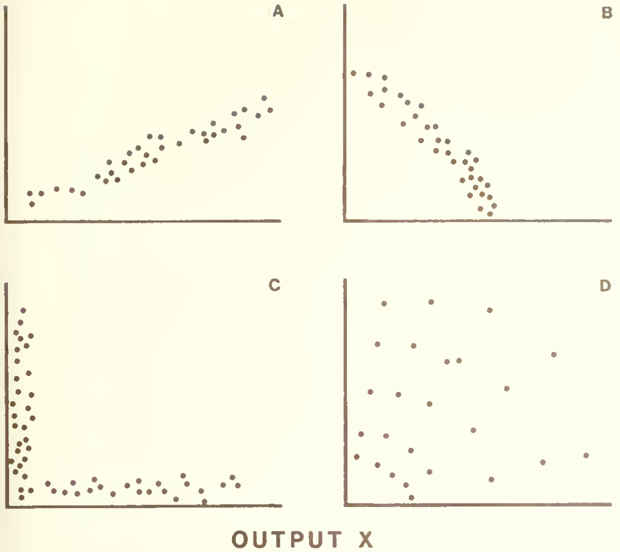
The third difference is that the ordinary linear programming formulations allow one to analyze a greater number of possible outcomes than does the MIP formulation. This can be illustrated most easily by comparing the example MIP formulation (table 3) with the comparable ordinary linear programming formulation described earlier in this section. The MIP formulation contained 45 project variables, which equaled the number of decision alternatives. The linear programming formulation contains one decision variable for each series of harvest alternatives in the MIP—five in all. These five decision variables can represent essentially an infinite number of harvesting alternatives for the area because each variable can assume fractional values.

Specifying Alternatives

Specifying alternatives is a critical step in the integer approximation to the theoretical joint production for the graphical and MIP approaches. The model is limited to choosing among only those alternatives provided. If only inefficient alternatives are specified, then the alternative identified as best will necessarily be inefficient.

Graphs a-d (fig. 6) illustrate this point. In graph a, the decision set (represented by the data) is too narrow with regard to tradeoffs between outputs X and Y. The actual optimum could lie on either side of this rather narrow band of alternatives. Graph b illustrates the opposite, alternatives span the range between outputs, but have little range with regard to scale. The optimal scale could be larger or smaller. In graph c, projects are single-product oriented. The actual optimum may be a joint production alternative lying somewhere in the middle of this decision space. Finally, graph d illustrates a set of alternatives that span the decision space. We believe this to be the best strategy for specifying alternatives because it is the most likely to bound the actual optimal.

A drawback of the MIP formulation is that the distribution of decision alternatives is not visually apparent



igure 6.—Project alternatives that span the ecision space (graph d) versus several examples of alternative sets that do not graphs a-c).

ıs it is in the graphical approach. Perhaps it would be ıseful to plot project alternatives, even if the MIP approach is used. For problems containing more than two ›utputs, each combination of two outputs could be plotted for the alternatives. While not perfect, it would at east give a fair idea of the distribution of projects.

An apparent problem with the integer approach resented is that the number of alternatives that can be ncluded in a model is limited by the amount of time ıvailable for model construction. If alternatives are held o a modest number, say 40 to 50, there is a chance that ıone of the alternatives provide a good approximation of he true optimal—even if decision space is spanned as illustrated in graph d. If this is a concern, we suggest onstructing a second model that is comprised totally of lternatives in the portion of decision space identified as est with the first model. This would provide the ability o achieve a reasonably good approximation of the true ptimal without specifying the large number of alternatives that would be required to achieve the same outome with one model.

)perationally Viable?

One of the more attractive features of the MIP approach is that it lends itself to automation. Front-end lata processing software could be written for data entry nd matrix generation. Data entry could be made interctive, leading the user through the process and providıg error checking capability. There are numerous ways uch a program could be structured. At most, users ould be required to enter unit values and costs and utput quantities for each project. However, it would kely be possible to structure the process so only codes lentifying categories for unit costs and output quantiies need be entered. Costs and outputs would then be alculated from information stored internally, either in he form of tables or prediction equations.

A second attractive feature of this MIP formulation is the small size and simplicity—at least when compared to other mathematical programming formulations used in forestry. It is easy to solve and sufficiently small to be processed on a small computer.

Given the front-end software described above, we believe there is little question that the MIP approach for solving discrete joint production models would be operationally viable. It should be no more difficult to use than simulation programs, which are commonly used by resource managers with little or no training in operations research.

Summing It Up

As we have discussed, the discrete joint production model provides the same type of analysis as the continuous joint production model of economic theory. It provides the capability to analyze the economic efficiency of multiple-use management, both in terms of type of project and scale of project (for example, in the timber sale example both the type of cutting alternatives and amount of harvesting were included in the analysis).

The graphic approach to solving these discrete models has the advantage of requiring little in the way of equipment—only paper, pencil, and a straightedge. Little or no start-up time is involved—no need to write computer software or to learn how to use existing software. In addition, it rather clearly depicts the nature of economic efficiency in multiple-use production. The graphic approach, however, has some real limitations enumerated earlier (limited to two outputs and difficulty in conducting intertemporal analysis). Because of these, the graphic approach will likely be limited to special applications.

The MIP approach provides some important advantages over the graphic approach. It lends itself well to automation. With the appropriate software, users relatively inexperienced in computer modeling could conceivably build and solve such a model very efficiently. Next, the mathematical programming formulation provides some very useful sensitivity analysis capability. Finally, the MIP approach is not limited to two outputs and can handle intertemporal analysis more easily.

The discrete joint production model provides a somewhat different type of analysis than what resource allocation mathematical programming formulations common in forestry generally provide. In "ordinary" linear programming formulations, output is a linear function of acres treated, for each decision variable. Questions regarding scale of activities can be addressed only rather crudely by varying the level at which constraints are imposed. The discrete joint production model, on the other hand, can handle nonlinear output and cost relationships, making it a more effective approach by analyzing questions of scale. This can be important, particularly when wildlife and recreation outputs are among the joint products.

The second difference is that the spatial arrangement of activities can be identified more precisely in the discrete joint production model. This is advantageous when location of an activity affects cost or outputs.

Third, the discrete joint production model requires that the user consider fewer alternatives than what can be considered in "ordinary" linear programming formulations. In some respects, the model we have presented has characteristics of both simulation and optimization. Like simulation, it requires the user to formulate whole alternatives. But it does provide some of the optimization and sensitivity analysis capabilities of mathematical programming. Because of the limited number of alternatives that can be handled effectively, the joint production model is best suited to problems of a relatively small geographic scope.

In conclusion, we believe the modeling approach presented in this paper is a practical and useful tool for conducting multiple-use efficiency analysis. The potential lies not as a substitute for current forest planning methods, but rather as a tool to aid in identifying efficient management prescriptions to place in forest planning models, and as a means of analyzing projects for implementation. It would be most effective when spatial arrangement of activities is important, and when outputs or costs are nonlinear with respect to acres treated.

REFERENCES

Gilbert, B.; Johnson, K. N.; Crim, S. FORPLAN Version 2 (DE FORPLAN) user's guide. Unpublished draft on file at USDA Fort Collins Computer Center under file name V2FORPLAN*USERGUIDE.RCNAM. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Fort Collins Computer Center; 1982.

Gregory, G. R. An economic approach to multiple use. Forest Science. 1: 6-13; 1955.

Hillier, F. S.; Lieberman, G. J. Introduction to operations research. 2d ed. San Francisco: Holden-Day, Inc.; 1974. 800 p.

Lyon, L. J.; Lonner, T. N.; Jones, J.; Marcum, C. L.; Weigand, J.; Sall, D. Montana cooperative elk-logging study. Progress report for period January 1 through December 31, 1981. Missoula, MT: U.S. Department of Agriculture, Forest Service; 1982. 89 p.

Muhlenberg, N. A method for approximating forest multiple-use optima. Forest Science. 10: 209-212; 1964.

Navon, D. I. Timber RAM: a long-range planning method for commercial timber lands under multiple-use management. Research Paper PSW-70. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station; 1971. 22 p.

Plane, D. R.; McMillan, C., Jr. Discrete optimization: integer programming and network analysis for management decisions. Englewood Cliffs, NJ: Prentice-Hall, Inc.; 1971. 251 p.

U.S. Department of Agriculture, Forest Service. Resource allocation analysis (a user's manual). Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Watershed Systems Development Unit; 1975. n.p.

*U.S. GOVERNMENT PRINTING OFFICE: 1985-0-576-040/10026

Jones, J. Greg; Schuster, Ervin G. An application of discrete optimization for developing economically efficient multiple-use projects. General Technical Report INT-178. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1985. 16 p.

A discrete version of the continuous joint production model in economic theory is presented for use in designing multiple-use projects and identifying efficient management prescriptions for forest planning. Data requirements are less demanding than the continuous theoretical model, yet some of the more important features are maintained. Models can be formulated graphically or as mixed-integer programming problems that are easily solved via computerized routines.

KEYWORDS: economic analysis, multiple-use, decision making, mixed-integer programming

The Intermountain Station, headquartered in Ogden, Utah, is one of eight regional experiment stations charged with providing scientific knowledge to help resource managers meet human needs and protect forest and range ecosystems.

The Intermountain Station includes the States of Montana, Idaho, Utah, Nevada, and western Wyoming. About 231 million acres, or 85 percent, of the land area in the Station territory are classified as forest and rangeland. These lands include grasslands, deserts, shrublands, alpine areas, and well-stocked forests. They supply fiber for forest industries; minerals for energy and industrial development; and water for domestic and industrial consumption. They also provide recreation opportunities for millions of visitors each year.

Field programs and research work units of the Station are maintained in:

Boise, Idaho

Bozeman, Montana (in cooperation with Montana State University)

Logan, Utah (in cooperation with Utah State University)

Missoula, Montana (in cooperation with the University of Montana)

Moscow, Idaho (in cooperation with the University of Idaho)

Provo, Utah (in cooperation with Brigham Young University)

Reno, Nevada (in cooperation with the University of Nevada)

United States
Department of
Agriculture

Forest Service

**Intermountain
Forest and Range
Experiment Station
Ogden, UT 84401**

General Technical
Report INT-179

March 1985

Biology and Management of the Gambel Oak Vegetative Type: A Literature Review

**Kimball T. Harper
Fred J. Wagstaff
Lynn M. Kunzler**

THE AUTHORS

KIMBALL T. HARPER is a professor of botany and range science at Brigham Young University, Provo, Utah. He has held professorships at the University of Utah and has been Chairman of the Botany and Range Department at BYU. He holds B.S. and M.S. degrees from BYU and a Ph.D. from the University of Wisconsin.

FRED J. WAGSTAFF is a range economist at the Intermountain Station's Shrub Sciences Laboratory, Provo, Utah. He has worked as a resource economist in several locations. He holds B.S. and M.S. degrees from Utah State University and a Ph.D. from Brigham Young University.

LYNN M. KUNZLER was a research assistant at the time of writing. He holds a B.S. degree from Weber State College and an M.S. degree from Brigham Young University. He is currently employed by the Department of Natural Resources, State of Utah.

PREFACE

This publication is a product of cooperative research and management efforts by the Intermountain Forest and Range Experiment Station, Intermountain Region, Forest Service, U.S. Department of Agriculture, and Brigham Young University to explore new resource management opportunities, such as fuel wood production from Gambel oak. This cooperative effort will provide a unique opportunity to develop a better scientific basis for multiple-use management of Gambel oak. Joint development and evaluation of the consequences of various management strategies to produce products such as fuel wood will help assure continued (and perhaps enhanced) productivity of Gambel oak, minimize adverse environmental impacts of management, and help maintain values of the multiple resources of the Gambel oak habitat.

ACKNOWLEDGMENTS

This study owes a great deal to Dr. Juan Spillett, formerly at the Uinta National Forest, for initiating the study and making funds available. Kaye Thorn drew the cover illustration.

RESEARCH SUMMARY

A total of 231 pieces of literature dealing with Gambel oak (*Quercus gambelii* Nutt.) covering the period 1890 through 1983 are reviewed. The basic biology of the species, its distribution in relation to climate and soils, and its ecology and successional dynamics are discussed. Additional discussions consider use of oak by wildlife, domestic grazing animals, and man and management of oak-dominated vegetational types with fire, herbicides, and mechanical treatments.

Decadent stands of oakbrush can be rejuvenated most economically by harvest for fuel wood on gentle slopes and by controlled burns on steep or rocky sites. Twice-over anchor chaining also is reasonably economical, but it results in loss of fuel wood and is not always feasible because of steep or rocky terrain. Chemical control of oak is possible, but may cause serious side effects and have off-target impacts. Nevertheless, chemical treatments are often advisable on small areas managed for special purposes. Because oakbrush tends to sprout prolifically after above ground parts are removed, areas treated for forage enhancement should be immediately seeded with competitive herbs and grasses or heavily grazed by browsing animals such as sheep, goats, or deer to keep stands open and producing growth that is within reach of and usable by browsers.

CONTENTS

Biology and Management of the Gambel Oak Vegetative Type: A Literature Review

Kimball T. Harper
Fred J. Wagstaff
Lynn M. Kunzler

NTRODUCTION

Our analysis of Kuchler's (1964) vegetative map of the nited States indicates that Gambel oak (*Quercus gamlii* Nutt.) is an important component of the vegetative ver of 9.3 million acres (about 3.76 million ha) in the estern United States. Most of that acreage lies within e States of Arizona, Utah, and Colorado (about 49, 29, d 21 percent, respectively, of the total area dominated the species). The species is also important, but rarely minant, on lower elevation slopes of mountains in rthwestern New Mexico and northern Mexico (Kearney d Peebles 1960; Lamb 1971).

The Gambel oak type usually occurs as a woodland of v-growing trees between the pinyon-juniper and pondesa pine zones of mountains within the species' range erriam 1890). Such oak woodlands provide excellent otection against soil erosion. A variety of animals inding elk, mule deer, cottontail rabbits, ruffed grouse, d bandtailed pigeons derive all or at least part of their stenance from Gambel oak communities (Hayward 48; Kufeld 1970a; Reynolds and others 1970; Lamb 71; Pederson 1975; Steinhoff 1978).

AXONOMY AND DISTRIBUTION

axonomic Affinities

Gambel oak belongs to the white oak section of the nus *Quercus*, family FAGACEAE (USDA Forest Serv 1937). The species is normally a tall shrub or small e (Dayton 1931), but Barger and Ffolliott (1972) show photograph of a 76-ft (23.2-m) tall Gambel oak tree in izona. A 48-ft (14.6-m) tall tree with a basal stem cirmference of 18.5 ft (5.6 m) has been reported from the adwaters of Deep Creek near Navajo Lake in southstern Utah (Anon. 1948). Reports that the tree was re than 1,000 years old at that time (Kay 1948) appear be unsubstantiated by ring counts.

Gambel oak has considerable morphological variation ich prompted earlier taxonomists to recognize as ny as eight additional species within the populations w included within *Q. gambelii* (Harrington 1954; cker 1961, p. 203). Through hybridization with and rogression of genetic material into other oak taxa that me in contact with some of its populations, *Q. gamlii* has influenced the evolution of several other oak species. *Quercus undulata* (Tucker 1961) appears to have derived many of its morphological and ecological traits from *Q. gambelii*. Indeed, much evidence suggests that *Q. undulata* is the result of hybridization of *Q. gambelii* with *Q. grisea* (Tucker 1961), *Q. havardii* (Tucker 1970), and *Q. turbinella* (Tucker and others 1961) at different times and places. *Quercus muehlenbergii*, *Q. mohriana*, and *Q. arizonica* are also believed to have hybridized with *Q. gambelii* at various times in the past and left descendent populations that are now included within the *Q. undulata* complex (Tucker 1961, 1963), but such populations do not appear to be of great importance in evolution of the *Q. gambelii* complex (personal communication, J. Tucker). To our knowledge, chromosomal numbers have never been reported for *Q. gambelii* and contributors to the *Q. undulata* complex.

Cottam and others (1959) postulated that during a warm interval covering a period of several thousand years immediately before A.D. 1, *Q. turbinella* moved far north of its current northern limits in southern Utah and hybridized with *Q. gambelii* as far north as Ogden, Utah. Antevs (1955) first discussed such a warm period for the Western United States and called it the Altithermal. Modern paleoclimatologists working in the American Southwest refer to that interval as the Hypsithermal (LaMarche and Mooney 1972).

Cooling after the warm period was believed to have eliminated *Q. turbinella* north of Washington County in southwestern Utah, but its hybrids with *Q. gambelii* were able to persist in northern Utah within the thermal inversion zones that rim most of the valleys along the eastern edge of the Great Basin. Harper and Alder (1970) caution, however, that in the absence of fossil material of *Q. turbinella* in northern Utah, an Altithermal incursion of that species into the area should not be assumed. Instead, the acknowledged hybrids of *Q. turbinella* and *Q. gambelii* in northern Utah may be the result of long-range pollination.

In a later report, Harper and Alder (1972) noted that *Q. turbinella* and all other southern plant species are lacking in the human midden heaps of dry caves that border the shores of ancient Lake Bonneville in northern Utah. Because those midden heaps span the entire period suggested by Antevs (1955) for the Altithermal climatic interval, the absence of *Q. turbinella* and other

southern plant species in the heaps weakens the hypothesis that *Q. turbinella* migrated into northern Utah in Altithermal times. More recently, Wells (1983) reported on plant fossils found in woodrat middens that date to the Altithermal period in southern portions of the Great Basin and adjacent areas. Middens of the Altithermal were found at three locations: Rainbow Canyon in southeastern Nevada, the Wah-Wah Mountains in west-central Utah, and Snake Range in east-central Nevada. Although all these locations are ideally situated to receive migrants from the south, none of them showed Altithermal influxes of species now confined to more southerly locations. Although the data are still too sketchy for firm conclusions, there is as yet no fossil evidence to support the idea of a long migration northward by *Q. turbinella* (or any other species for that matter) during the Altithermal.

Maze (1968) believed that *Q. gambelii* had hybridized with *Q. macrocarpa* in northeastern New Mexico and in the Black Hills of South Dakota. He postulates that *Q. macrocarpa* migrated westward into New Mexico sometime during the more moist periods of the Pleistocene and has subsequently died out. He considered that *Q. gambelii* migrated far east into the Black Hills in the Altithermal and then disappeared from that outpost with the return of more moist and cooler conditions. Neilson and Wullstein (1983) also held that *Q. gambelii* reached the Black Hills during the Altithermal, but concluded that the period had more rather than less precipitation during the growing season.

Geographic Range

Gambel oak occurs within the ponderosa pine zone (lower transition zone in the Merriam system) of the Central Rocky Mountain Region of western North America (fig. 1). Present distribution of the species runs from northern Utah (Brigham City area) south through the mountains of Arizona into northern Mexico. In the east-west direction, Gambel oak extends across central and southern Utah, appears in isolated populations in the Charleston Mountains of southern Nevada, and is common across all but the southwestern corner of Arizona. The species is found throughout all except the southeastern portion of New Mexico and in isolated pockets in western Texas. In Colorado, Gambel oak occurs in all of the mountains except the Front Range of the Rockies. It enters south-central Wyoming in Carbon County. The species is unexpectedly absent from all but the western and southern edges of the Uinta Basin and from most of the Uinta Mountains where it is present on calcareous rocks and alluvial sediments of both the western and eastern ends of the range (Graham 1937; Hayward 1948; Christensen 1949; Clokey 1951; Allman 1952; Ream 1960 and 1963; Wells 1960; Grover and others 1970b; Reynolds and others 1970; Little 1971; Steinhoff 1981). Allman (1952) and Mason and West (1970) indicate that areas dominated by Gambel oak are subject to recurrent wildfires.

The absolute elevational range of Gambel oak is between 3,250 and 10,200 ft (991 and 3 109 m) (Sampson 1925; Dayton 1931; Graham 1937; Hayward 1948; Baker 1949; Christensen 1949, 1950; Allman 1952, 1953; Cottam and others 1959; Ream 1963; Reynolds and others 1970; Horton 1975; Steinhoff 1981). The elevational range limits are widest in the southern portions of the species' range and become progressively narrower as one moves northward (Neilson and Wullstein 1983). Steinhoff (1981) considered the optimal elevational range to be 7,100 to 9,000 ft (2 164 to 2 743 m) in southwestern Colorado. In northern Utah, stands of the species are best developed between 5,500 and 7,500 ft (1 676 and 2 286 m). Geographical distribution of the species appears to have been rather stable for several hundred years (Brown 1958), although some recent movement toward lower elevations in northern and central Utah has been reported by Christensen (1949, 1950) and Rogers (1982).

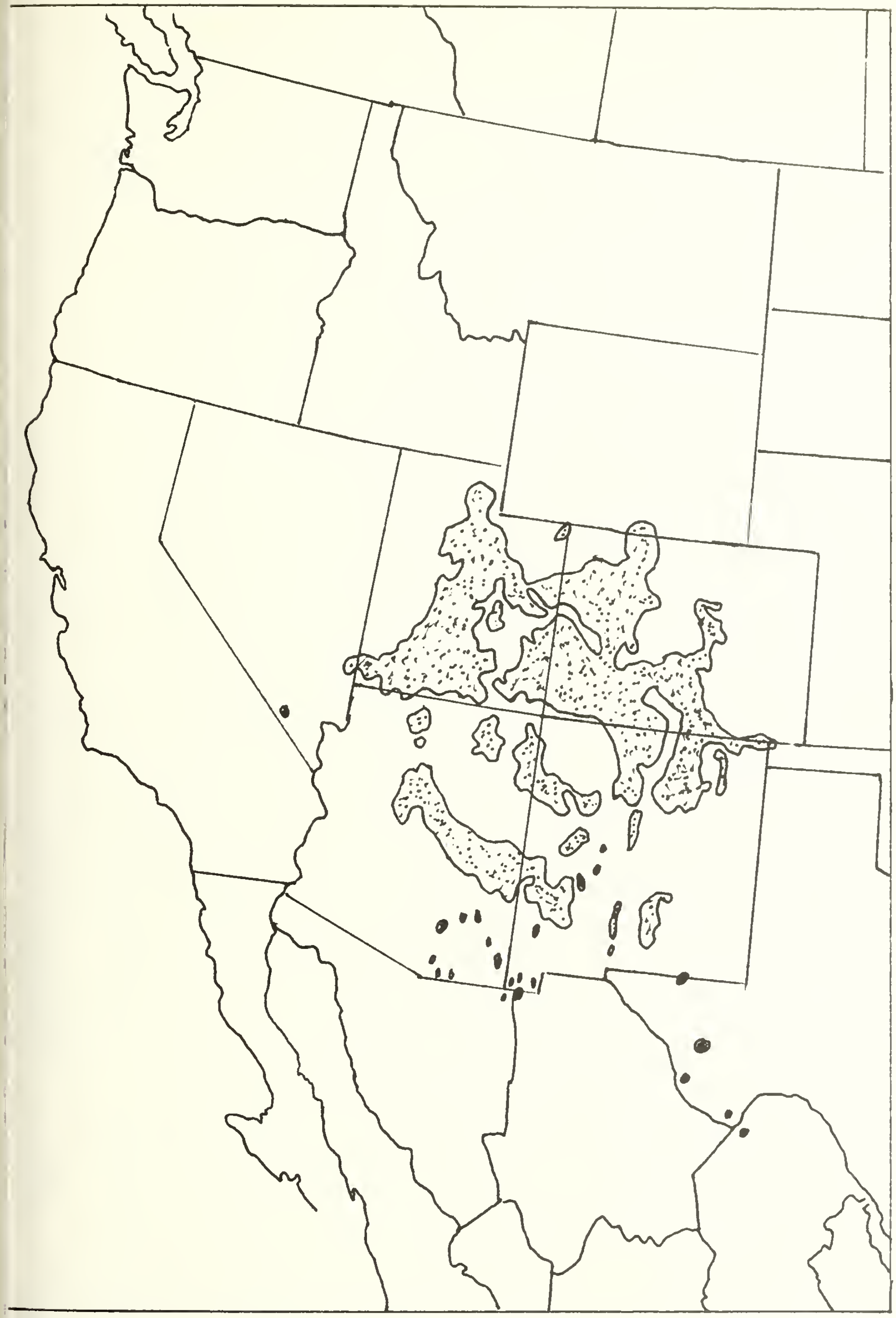
Climatic Relationships

Oakbrush populations commonly experience a yearly temperature range of 100 °F (55.6 °C) (Price and Evans 1937). The species often occurs in areas that experience subzero winter temperatures and a mean annual temperature of between 45 and 50 °F (7 and 10 °C). In central Utah, long-term averages show 90 frost-free days per year in the oakbrush zone (Price and Evans 1937). Precipitation within the oak zone varies between 15 and 22 inches (38 and 56 cm) per year. In the northern part of the species' range, summers are usually dry with occasional small thunderstorms (Baker and Korstian 1931; Price 1938; Lull and Ellison 1950; Allman 1952, 1953; Christensen 1959; Eastmond 1968). Summer precipitation is more abundant in southern parts of the range; the amount of summer rainfall tends to increase steadily with declining latitude (Neilson and Wullstein 1983).

Grover and others (1970b) described Gambel oak as a good indicator of climatic conditions, because it does not occur in areas that receive less than 10 inches of precipitation or where subfreezing temperatures exist over long periods of time. Christensen (1955) suggested that short growing seasons at higher elevations are the limiting factor for upward movement of this oak. Cottam and others (1959) and Erdman (1961) concluded that occasional minimum temperatures that exceed the tolerance limits of the species determine the northern limits of oakbrush. Neilson and Wullstein (1983) presented good evidence that deficient summer precipitation combined with frequency and intensity of spring frosts limited the species range in the north.

Soil Relationships

Soil studies suggest that most of the soils within the oakbrush zone are derived from limestone, limey sandstones, and shales or granitic parent materials (Baker and Korstian 1931; Markham 1939; Allman 1952, 1953; Nixon 1961, 1967; Ream 1963; Tew 1966, 1967, 1969; Steinhoff 1978). In southwestern Colorado, oak most often occurs on Argic Pachic Cryoboroll and Argic Cryoboroll soils (Steinhoff 1981). Texture of soils developed under oak ranges from loam to silt loam. Soil moisture-holding capacity is high because of an abundance of silts and clays and an organic content from 5.0 to 7.5 per-



gure 1.—Distribution of Quercus gambelii Nutt. (Little 1971).

nt; pH ranges from 5.9 to 8.0 with most readings ing circumneutral under oakbrush (Baker and Korstian 31; Price 1938; Allman 1953; Nixon 1967; Steinhoff 81). Jefferies (1965a), Tew (1966, 1967, 1969), Johnston d others (1969), Marquiss (1972), and Marquiss and ers (1971) reported that soil moisture depletion is reduced when Gambel oak is eliminated from a site, but herbaceous understory is left intact.

Steinhoff (1978) showed that Gambel oak is more tolerant of heavy clay soils or heavy clay horizons within the rooting zone than pines or junipers. In Colorado, serviceberry (*Amelanchier* sp.) is usually an important associated species with oak on heavier textured soils.

BIOLOGY

Reproduction and Dispersal

Gambel oak, in common with most deciduous wind-pollinated species, flowers before expansion of the leaves. The species is typically monoecious (Harrington 1954), but Tucker and others (1980) reported an aberrant flowering of Gambel oak in Utah in August 1978 in which many flowers in the unusual inflorescences contained both anthers and pistils. Individuals that produced the aberrant flowers in 1978 flowered normally in 1979 and produced strictly monoecious flowers (Tucker and others 1980).

Typically, the inconspicuous reddish pistillate flowers are borne in the upper leaf axils on new growth while the long, yellowish green, drooping male catkins are produced singly or in groups of several from around the base of the new shoots (Freeman and others 1981). Authorities differ concerning the relative time of maturation of the male and female reproductive organs of the species. J. M. Tucker (personal communication) considers Gambel oak flowers to be typically protandrous, but Garrett (1927) reported the species to be protogynous in northern Utah. Pistils are borne sessil in a cuplike involucre that ultimately becomes the acorn cap. Pistils are topped by three stigmas and are initially three celled and six ovuled, but only one of the ovules matures. In northern Utah, the species normally flowers in early May at its lower elevational limits (Garrett 1927; Brown and Mogenson 1972; Tucker and others 1980). Acorns mature in northern Utah in September and early October (Christensen 1955, and personal observation).

Freeman and others (1981) showed that Gambel oak on extremely xeric sites often failed to produce mature female flowers. In contrast, male catkins were produced in abundance on such sites. Neilson and Wullstein (1983) observed relatively more ovule abortion on xeric than more moist microsites. Both male and female flowers are produced in large numbers on moist sites. Freeman and others (1981) also showed that both male and female flowers of oak are produced at the top of the plant canopy, but flowers beneath the canopy are almost exclusively female.

Both flowers and leaves of the species are easily killed by frost once rapid growth begins (Sweeney and Steinhoff 1976; Neilson and Wullstein 1980b). We have observed the species to have new growth frozen back twice in the same spring in Salt Lake County, Utah. Oak foliage has been killed by frosts as late as July 4 in Utah mountains. Neilson (1981) noted that many Gambel oak seedlings planted experimentally at the northern edge of the species' range in Wyoming were killed by a spring freeze in 1979.

Mogensen (1972) reported an electron microscopic study of the egg apparatus of Gambel oak. Brown and Mogensen (1972) provided a detailed description of embryo development within the species' fruits. Singh and Mogensen (1975) described the ultrastructure of Gambel oak zygotes and early embryos. The fruit is formed and matures in a single growing season (Garrett 1927). The species does not produce heavy acorn crops every year anywhere within its range, and in many years no acorns at all mature (McCulloch and others 1965; Neilson and Wullstein 1980b). In heavy moisture years Gambel oak may produce over 331,000 acorns per acre (817 900 per ha), but in the average year near Flagstaf Arizona the species matures only about 188,000 acorns per acre (464 548 per ha) (McCulloch and others 1965). Stems of the species produce few acorns before they reach 2 inches (5.1 cm) diameter at breast height; acorn production rapidly declines once stems exceed 14 inches (35.6 cm) in diameter (McCulloch and others 1965). Ma imum fruit set appears to be achieved by healthy stems 12 to 14 inches (30.5 to 35.6 cm) in diameter (McCulloc and others 1965).

Seed (fruit) weight for Gambel oak appears not to ha been reported, but if acorns are similar in weight to those of *Q. turbinella*, each should weigh 0.046 to 0.053oz (1.3 to 1.5 g) (USDA Forest Service 1974). At that rate, the species should produce between 500 and 625 pounds of acorns per acre (560.5 and 700.6 kg/ha) i an average moisture year. Christensen (1955) noted tha in Utah acorns were heavily infected with seed-destroying larvae of lepidopteran and coleopteran insects. He found that more than 85 percent of the acorns stored over winter were destroyed by such pests Neilson (1981) reported that acorn destruction by insect larvae was greater in areas where autumn droughts we frequent and prolonged.

In the northern parts of its range, the species appear to reproduce rarely from acorns (Christensen 1949; Muller 1951; Neilson and Wullstein 1983), but in the southern portion of its range where summer rains are heavier and more reliable, seedlings are more common (Neilson and Wullstein 1980a, 1983). Nevertheless, Rogers' (1982) photo-pairs show some new oak plants that are apparently seedlings throughout the species' range in northern Utah. Neilson (1981) also observed seedlings in northern Utah. In contrast, the species is a vigorous vegetative reproducer. Reproduction is usually from slow-growing, freely branched rhizomes that give rise to a multitude of sparsely branched shoots (Muller 1951). Spread of established clones currently appears to be slow in both Utah (Christensen 1955) and Colorado (Brown 1958).

Numerous references show that Gambel oak sprouts profusely after burning (Baker 1949; McKell 1950; Frischknecht and Plummer 1955; Dick-Peddie and Moir 1970), mechanical crushing (Plummer and others 1966; Engle and Bonham 1980), or herbicide treatment (Heike 1964; Jefferies 1965b; Johnsen and others 1969; Marquiss 1973; Engle and Bonham 1980). Given the species' vigorous sprouting response to a variety of disturbances, one might suppose that it would be easy to transplant, but experience has shown no, or at best, poor transplanting success (Kelly 1970; Sutton and Johnson 1974). It is generally recognized that all oaks are difficult to propagate from cuttings, but Davis (197 has had reasonably good success with *Q. turbinella*, another oak species of the American Southwest. He use softwood cuttings with fully expanded leaves that had not yet hardened. Cuttings were immediately trimmed t two or three leaves, placed in a rooting medium of horticultural perlite and peat moss (1:1 ratio), and held

in a chamber that received water mist for 30 seconds every 5 minutes. Light intensity at leaf level was about 1600 fc; air temperature was 77 °F (25 °C).

Recently, Schier (1983) reported on his attempts to regenerate Gambel oak from rhizomes (underground axes with pith). Rhizome segments from 0.4 to 0.8 inch (1 to 2 cm) in diameter and 3.9 inches (10 cm) in length (average age of 12.2 years) were surface sterilized, sealed at cut ends with liquid paraffin, and planted 0.6 inch (1.5 cm) deep in moist vermiculite in planting trays. About 25 percent of the rhizome segments taken in summer (late July) showed some sprouting within 2 months under greenhouse conditions (77 °F days and 62.6 °F nights [25 °C and 17 °C]): rhizome segments that sprouted had an average of 3.8 (range 1 to 12) shoots per sprouted segment. Rhizomes taken too late in autumn (late September) occasionally required cold storage (121 days at 35.6 °F [2 °C]) before any sprouting occurred. Cold-treated rhizomes showed somewhat better sprouting success (54 percent of the segments with sprouts and 3.1 shoots per sprouted segment) than summer collections. Rhizome segments kept in a lighted growth chamber showed over six times as large a fraction with sprouts as comparable segments similarly treated, but kept in darkness (32.5 versus 5.0 percent with sprouts). Attempts to root shoots generated from rhizomes failed in all cases. Thus, shoot production from rhizomes is apparently not an acceptable propagation technique for Gambel oak.

Clonal growth helps the species survive in marginal environments and where competition is intense. Clonal growth also ensures great longevity of individuals and this slows the evolutionary rate (Muller 1951).

The species appears to occupy new locations through long-distance transport of acorns by such agents as bandtailed pigeons (*Columba fasciata*), scrub jays (*Aphelocoma coerulescens*), Stellar jays (*Canocitta stelleri*), or Lewis and acorn woodpeckers (*Asyndesmus lewis* and *Melanerpes formicivorus*) (Christensen 1949; Anderson 1975; Harper and others 1978). The Clark's nutcracker (*Nucifraga columbiana*) has been observed to move bristlecone pine seeds over 13 mi (21.7 km) in a single flight (Vander Wall and Balda 1977). It is conceivable that jays and bandtailed pigeons occasionally move acorns similar distances. Less distant dispersal is regularly caused by small mammals, such as the Utah rock squirrel (*Spermophilus variegatus*) (Rasmussen 1941). Once attained, the new territory is tenaciously held by vegetative reproduction (Christensen 1949; Brown 1958). Individual stems produced by vegetative reproduction remain attached to parental plants for long periods (Pendleton 1952).

Christensen (1957) and Rogers (1982) used historic photographs to document recent establishment of new oak clones and expansion of previously established clumps. Rogers stated that the increase in oak clones on the eastern rim of the Great Basin has been especially rapid since 1940, but he acknowledges that his estimates might be off by as much as 30 years due to the difficulty of detecting oak seedlings less than a foot tall in photographic records of landscapes. Similarly, Petersen (1954) showed that oak had increased its cover between 1939 and 1953 on Morris Watershed in Farmington Canyon in northern Utah. Christensen (1955) noted that the rate of expansion of oak clones in northern Utah averaged from 1.5 to 12 inches (3.8 to 30.5 cm) per year with about 4 inches (10 cm) being typical.

Physiology

Gambel oak is severely damaged by late spring frost. Although the species is often found above 8,000 ft (2 435 m) elevation in northern Utah (Allan 1962; Ream 1963; Crowther and Harper 1965) and above 9,000 ft (2 743 m) in southern Utah (Christensen 1950), its continued existence there seems to be related to the insulating effects of deep snow in the winter and delayed flowering in the spring (Allan 1962; Neilson and Wullstein 1980b). At higher elevations, Allan (1962) reported that the species seemed to not produce viable seeds. He believed that oak reached the higher elevations during the Altithermal interval of Antevs (1955). Normally, the species dominates an altitudinal belt above the pinyon-juniper zone and below the aspen or ponderosa pine zone (Markham 1939; Barger and Ffolliott 1972). Kunzler and Harper (1980) showed that oak recovered from fire much faster at lower elevations and on warmer south-facing slopes. Barger and Ffolliott (1972) reported that the species grew rapidly in both height and diameter early in life, but growth rates declined steadily with age. In contrast, Wagstaff (1984) showed little change in rate of increase in diameter during the first 100 years of life of oak stems in central Utah.

Keddington (1970) showed that water stress increased as the season progressed, but was always least at the highest elevations sampled. As expected, plants showed maximum stress at the end of warm sunny days. Keddington concluded that moisture stress could not control the upper elevational limits of oak, because stress decreased with elevation. Nevertheless, the smallest and least vigorous oak plants he studied occurred at the highest elevation site. Neilson and Wullstein (1983) showed that in northern Utah most mortality of oak seedlings experimentally planted into natural stands of the species occurred in summer, not winter. Of the winter mortality observed, most was at higher elevations, but summer mortality was heaviest at the lowest elevations considered. Nevertheless, summer mortality was high (always over 30 percent) even at the upper elevational limits naturally achieved by the species. On open microsites (without canopy shading), mortality of seedlings was 100 percent at upper elevational sites. Under canopy protection, some 60 percent of the seedlings survived the summer season at higher elevations. Neilson and Wullstein found that summer mortality was usually induced by dessication, while winter losses were most closely linked with spring frosts. Thus, Neilson and Wullstein offer strong empirical support for Keddington's (1970) and Christensen's (1949) conclusions that oak is limited at lower elevations by water stress and at higher elevations by competition, cold temperature, wind, and shorter growing seasons. Keddington also noted that when Gambel oak and canyon maple (*Acer grandidentatum*) grow in close association, "oak is

better able to withstand a lack of surface soil moisture than maple."

Dina (1970) and Dina and others (1973) reported on the pattern of water potential in Gambel oak stems. Dina (1970) and Dina and Klikoff (1973) found that neither net photosynthesis nor dark respiration rates of oak or canyon maple were much influenced by water stress. They reported that both species responded so similarly in that respect that differences in carbon metabolism could not be the reason for their differences in distribution. Oak is, however, distinctly less tolerant of shade than canyon maple (Christensen 1958). In contrast to oak and canyon maple, both net photosynthesis and dark respiration rates declined precipitously with increased moisture stress in boxelder maple (*Acer negundo*) (Dina and Klikoff 1973). Dina and others (1973) showed that both oak and canyon maple tended to be less water stressed at high than low elevations. They also noted that *Berberis repens*, a common understory plant associated in oak stands, showed no significant trend in moisture potential along an altitudinal gradient. The latter observation helps explain Neilson and Wullstein's (1983) observation that oak seedlings showed less variation in summer mortality under the canopy of established oaks than in adjacent openings along an altitudinal gradient. An overstory of vegetative cover apparently ameliorates water stress of understory plants.

Tew (1966) demonstrated that a Gambel oak stand with 65 ft^2 of basal area per acre (6.04 m^2 per ha) used 11 to 13 inches (27.9 to 33.0 cm) of water per year from the upper 8 ft (2.44 m) of soil. The species first extracted water from the surface 4 ft (1.2 m) of soil. Later, when surface soils are dry, the species drew water from the 4- to 8-ft (1.2- to 2.4-m) depth zone. Tew (1967, 1969) showed that Gambel oak depleted 3.0 inches (7.6 cm) more water from the soil than perennial range grasses on the same site. Removal of oak followed by sprouting resulted in a return to precut water use rates in 3 years.

Neilson and Wullstein (1979, 1983) noted that Gambel oak seedlings rarely survived (80 percent mortality) in the northwestern portion of the species' range, but seedling survival was better in New Mexico and Arizona where summer precipitation is common. They concluded the northern range limit of the species is controlled more by summer drought than cold winters as some had concluded earlier (Cottam and others 1959). Neilson and Wullstein also stated that drier summers on the northern edge of the species' range rendered areas below 5,000 ft (1 524 m) uninhabitable for the species. At the same time, declining temperatures and more frequent late spring frosts in the north largely eliminated oak from terrain above 8,500 ft (2 591 m). They showed that mortality of Gambel oak seedlings was far more dependent on moderate microsites (understory positions) on the northern than the southern edge of its range. As the northern edge of the range of oak was approached, increasingly more inhospitable conditions on both the lower and upper elevational limits confined the species to a progressively narrower elevational zone within which there were fewer microsites capable of supporting seedlings. The combination of a smaller exploitable elevational zone and fewer "safe" sites for reproduction within that zone has apparently halted the northward migration of Gambel oak.

Crowther and Harper (1965) showed that Gambel oak and a large number of other shrubs are more competitive than aspen on soils that store little water and are derived from quartzite. Aspen dominates limestone strata in Big Cottonwood Canyon, Salt Lake County, Utah, to the near exclusion of oak. Ream (1963) showed that oak in northern Utah typically occurs on soils that are slightly acidic and of loamy texture. Arnold and Olson (1962) found oak on neutral to moderately acidic soils of medium texture: drainage of oak-dominated soil was always good. Yake and Brotherson (1979) have described several soil characteristics associated with the oak-serviceberry type in central Utah. They found oak to perform relatively better than serviceberry on the deepest, best developed soils encountered.

Brown (1958) found that oak stems in west-central Colorado rarely lived longer than 80 years. Similarly, Sweeney and Steinhoff (1976) found that only 1 percent of 728 oak stems survived more than 80 years. They found no stems that were more than 100 years old. Brotherson and others (1983) estimated that over 6 percent of the Gambel oak stems they studied in Navajo National Monument, Ariz., exceeded 80 years of age; the oldest stem in their sample was 103. More than 90 percent of the stems encountered in long-established clones were less than 10 years old. Sweeney and Steinhoff (1976) found that oak consistently lived longer than aspen on common sites in southwestern Colorado.

Sweeney and Steinhoff reported that growth initiation by Gambel oak required about a 2-week period with root zone temperatures at or above 39.2 °F (4.0 °C). Late-lying snow maintained soil temperatures below 39.2 °F (4.0 °C) and retarded initiation of growth. In contrast, the duration of oak twig elongation varied only between 24 and 27 days in 4 years of study, regardless of ambient temperature conditons. Thus, twig elongation appeared to be genetically controlled (Sweeney and Steinhoff 1976). In the same study, production of annual browse by oak appeared to depend primarily on food stored in the buds, because it was more closely correlated with summer precipitation of the preceding year than with either winter or spring precipitation.

Tissue chemistry of Gambel oak has been studied by few workers. Dayton (1931) reported that young shoots contained 4 to 10 percent tannic acid. Nastis and Malechek (1981) found that immature terminal twigs with their leaves contained 11.1 percent tannin. In mature twigs, tannin content dropped to 8.7 percent. Dietz (1958) showed that Gambel oak leaves were relatively high in protein in late spring and late summer, but stems were always low in protein. Kufeld and others (1981) reported an average of 5.1 percent crude protein in Gambel oak twigs (current growth only and without leaves) in January; values were similar throughout Colorado. The same twigs averaged 27.8 percent soluble carbohydrate, 3.9 percent ether extract, and 4.7 percent ash (4.0 percent soluble ash). In vitro digestible dry matter of the twigs averaged 28.1 percent. For comparison,

agebrush (*Artemisia tridentata*) current year twigs (with eaves, no inflorescences) taken at the same time as the ak twigs had average contents of 9.9 percent crude protein, 43.2 percent soluble carbohydrate, 5.3 percent ether xtract, and 4.6 percent ash. In vitro digestibility of the agebrush samples averaged 49.9 percent. Carotene content of oak leaves is consistently high, but their crude at level is low (Dietz 1958). Smith (1957) showed that, n their leafless winter condition, Gambel oak twigs are ow in protein, ether extract, nitrogen-free extract, and otal digestible nutrients. The comparative summary of rowse plant forage values by Welch and others (1983) hows Gambel oak to rank at or near the bottom of the pecies considered for total digestible nutrients, dry matter digestibility, and crude protein content. Engle and Bonham (1980) demonstrated that the nonstructural carbohydrate content of Gambel oak rhizomes from young prouts was lowest midway through the leaf expansion rocess. Nonstructural carbohydrate levels in rhizomes f mature stems had been previously reported to be ighest at the time when leaves reached maximum expansion (Marquiss 1968).

The anatomy of Gambel oak wood is described in etail by Saul (1955). The wood is ring porous with conpicuous uniseriate or multiseriate rays. The wood is eavy (natural wood specific gravity of 39.6 lb/ft^3).63 kg/dm^3]), hard, and very strong (Barger and Ffolliott 972). Barger and Ffolliott showed that oak wood conains many compounds that can be leached away by hot ater and ethyl alcohol plus benzene extractants; an verage of 10.6 percent of the dry weight of unextracted ood was leached away in the extraction process. The reen wood of oak shrinks more than any other species n table 1, and it has a strong tendency to "check" and cup" as a result. Ovendry wood of Gambel oak is estiated to weigh 3,168 lb (1 437 kg) per cord by the ame authors. Fuel research by fire management scienists showed that downed Gambel oak wood retained a igh specific gravity in all size classes. Sackett (1980) ound naturally fallen oak debris to have the greatest pecific gravity in all size classes (0- to 3-inch [0- to .6-cm] diameter range) of eight tree species surveyed in ight different National Forests of Arizona and New Iexico. Average diameter of oak branches was slightly rger than the average for other species sampled.

On a unit volume basis, the energy content of Gambel ak wood is higher than that of any other associated ree species in the Southwestern United States (table 1). he data (Barger and Ffolliott 1972) demonstrate that he energy content per unit volume of oak wood is about 2 percent greater than for ponderosa pine wood, 18 perent greater than pinyon, and 24 percent more than Itah juniper wood. By interpolation from ponderosa ine, which is common to both Barger and Ffoliott's 972) and Kolstad's (1976) studies, we infer that oak ood contains 52 percent more energy per unit volume han wood from quaking aspen (*Populus tremuloides*) nd 36 percent more energy than lodgepole pine (*Pinus ontorta*) wood.

Table 1.—Comparative thermal energy content of the woods of five major tree species of southwestern woodlands; data from Barger and Ffolliott (1972)

Species	Energy content[1] (thousands of British thermal units/ft^3 [kcal/g])	
Juniperus monosperma (oneseed juniper)	243	(4.77)
J. osteosperma (Utah juniper)	274	(4.77)
Pinus edulis (pinyon)	289	(5.08)
P. ponderosa (ponderosa pine)	239	—
Quercus gambelii (Gambel oak)	340	(4.77)

[1]Based on assumption of following weights (ovendry) in grams per cubic centimeter of wood: *J. monosperma*, 0.453; *J. osteosperma*, 0.511; *P. edulis*, 0.506; and *Q. gambelii*, 0.634. Specific gravity of *P. ponderosa* was not available for these thermal studies.

Toxic Properties

Where abusive grazing pressure has eliminated palatable species from Gambel oak stands, browsing animals may be forced to consume enough oak to produce sickness or death (Marsh and others 1919; Dayton 1931; Stoddart and others 1949; Muenscher 1957; USDA Agricultural Research Service 1968). The poisonous agents are generally considered to be tannins (USDA Agricultural Research Service 1968), but other chemicals may also be involved (Muenscher 1957). The plant is most dangerous in the spring when tannin concentrations are maximum (USDA Agricultural Research Service 1968), but if animals are forced to consume enough of the plant, it is dangerous in any season (Muenscher 1957). Normally, up to 50 percent of the diet can consist of oak without trouble; when oak contributes 50 to 70 percent of the diet, sickness almost always follows, and when oak makes up over 75 percent of the diet, death often results (USDA Agricultural Research Service 1968). Toxicity is enhanced by freezing; young foliage turned black by frost is especially dangerous (Stoddart and others 1949). Leaves are the principal sources of tannins, but acorns also can be dangerous (Muenscher 1957).

Apparently only cattle are in danger of oak poisoning (Stoddart and others 1949). Goats seem more tolerant of oak tannins than other domestic livestock, but even they show large fecal nitrogen losses when tannin intake is high (Nastis and Malechek 1981). Symptoms of poisoning in cattle include gaunt, "tucked-up" appearance, constipation, emaciation, dark urine, and mucous and blood in feces followed by profuse diarrhea, weakness, unwillingness to follow the herd, and collapse (Marsh and others 1919; USDA Agricultural Research Service 1968). The symptoms closely parallel those of cattle "summer sickness," an ailment long recognized on oak ranges in Utah (Marsh and others 1919).

Insect Pests and Diseases

A variety of insects have been reported to utilize Gambel oak. Knowlton (1941) found two species of aphids belonging to the genus *Myzocallis* to occur on scrub oak throughout Utah. Brewster (1951) found that eight species of wasps of the family Cynipidae formed galls on leaves and stems of scrub oak in Salt Lake County, Utah. Individual trees were often attacked by multiple species of wasps. Even though individual trees bore numerous galls, the effect did not appear to be serious for the tree. The cynipid plant parasites were themselves parasitized by wasps of the family Chalcidae. The chalcid wasp oviposits on cynipid larvae in developing galls. In many galls, chalcid adults emerge. Grundmann (1951) gave a detailed description of the development of galls of the wasp (*Andricus pilula*) on Gambel oak near Salt Lake City. Galls usually occurred only on leaves less than 5 ft (1.5 m) above ground and on isolated trees or trees on the edge of isolated clones. Only oaks below about 6,000 ft (1 829 m) elevation were affected. Galls usually appeared within 3 or 4 days after leaf emergence; eggs had apparently been deposited in the bud during the preceding autumn. Larval development required 17 to 21 days, and another 8 to 10 days were required for development of pupae. Adult cynipid wasps emerged from galls during the early part of June.

Grundmann and Evans (1952) studied the galls of three cynipid wasps (*Andricus pilula, Cynips hirta undulata*, and *Xanthoterus eburneum*) on Gambel oak for the presence of bacteria in the galls. All galls were free of bacteria, thus tissue hypertrophy must have been induced by wound, egg, or larval hormones.

Evans and Grundmann (1954) made further observations on possible bacterial commensals in cynipid wasp leaf galls on oak near Salt Lake City, Utah. They investigated galls of *Cynips hirta undulata, Collirhytis juvenca, Dishlocapsis rubens, Plagiotrochus frequens*, and an autumnal gall of *Andricus* sp. All galls were found to be free of bacteria.

Brown (1958) occasionally found Gambel oak in Colorado defoliated by butterfly looper (*Lambdina punctata*). Remington (1960) found another lepidopteran larva (*Hypaurotis chrysalus*) feeding on Gambel oak. Furniss and Barr (1975) reported that a flatheaded borer of the beetle family Buprestidae bores in the wood of dead or injured stems of oak, but the borer does not seem to cause plant mortality. Furniss and Barr noted that larvae of several beetles belonging to the genus *Agrilus* burrow in the phloem of living oak stems and sometimes girdle them, thus causing death. Nevertheless, these insects rarely kill whole trees. They also noted that flatheaded borers of the genus *Anthaxia* feed in the phloem of oak stems and are often very host specific.

The tent caterpillar (*Malacosoma distria*), a lepidopteran, prefers aspen but sometimes defoliates oak, too (Furniss and Barr 1975). There are no known cases of this caterpillar's occurrence on Gambel oak, however.

The fungus *Polyporus dryophilus* causes heart rot in the stems of Gambel oak throughout the species' range (Hedgcock and Long 1914). Heart rot appears to be common in only the largest and oldest oak stems in Utah (personal observation). The imperfect fungus *Articularia quercina* causes development of witches' brooms on Gambel oak throughout its range. The disease is particularly conspicuous on the east slope of Mount Nebo in central Utah (Hawksworth and Mielke 1962). Although witches' brooms disfigure individual oaks, death rarely results from the disease.

COMMUNITY COMPOSITION

Regional Variation

Although Gambel oak communities are best developed on sloping upland sites, the species also regularly occurs along slope bases adjacent to streams (Allan 1962; Brotherson and others 1980) and on river floodplains in southern Utah (Flowers 1959), southern Colorado and northern New Mexico (Woodbury and others 1961), and western Colorado (Woodbury and others 1962). In such situations, oak is associated with species such as sandbar willow (*Salix exigua*), wild rose (*Rosa* spp.), hawthorn (*Crataegus douglasii*), and boxelder maple.

Community composition on uplands is surprisingly uniform throughout the range of Gambel oak (table 2). Only a few genera appear in the north in this community that do not also do well in the south; balsamroot (*Balsamorhiza*), waterleaf (*Hydrophyllum*), ninebark (*Physocarpus*), mules ears (*Wyethia*), and sedges (*Carex*) are some of the members of this group. Although associated species often change from place to place, the generic makeup of the community is quite uniform (Dixon 1935; Ream 1963; Cronquist and others 1972; Kufeld and others 1973; Steinhoff 1978; Brotherson and others 1980). That fact probably means that oak is, as Grover and others (1970a) have suggested, a good predictor of a peculiar kind of microhabitat. Throughout most of its range, Gambel oak is associated with maples, serviceberries, sagebrushes, mountain-mahogany species, pines, snowberries, fleabanes, peavines, lupines, goldenrods, wheatgrasses, fescues, and bluegrasses (table 2).

Regional variation in the fauna associated with the Gambel oak type is shown in table 3. Some animals appear only in the southern portion of the oak type. The bandtailed pigeon, Merriam turkey, Abert squirrel, and javelina are representative of such southern animals. Species that appear to be primarily of northern distribution include blue grouse, ruffed grouse, magpie, snowshoe hare, and badger.

To date, little work has been done on subdividing the Gambel oak community into habitat types that differ significantly in site quality for oak or in other characteristics that have significant ramifications for management of resources associated with this community. In Colorado, Steinhoff (1978) recognized seven different oak brush associations with five successional stages in each. Although there is a high degree of vegetational similarity among Steinhoff's subgroups, each can be recognized by the presence or absence of certain indicator plants (for example, juniper, serviceberry, or ponderosa pine).

ıble 2.—Plant species most often associated with Gambel oak in various parts of its range. Only one reference is cited to establish a species' presence in a region. Each species may appear in zones other than those listed, but its occurrence there was not found in the literature. Plant nomenclature follows Welsh and Moore (1973).

Species	Common name	Zone[1]	Source of information
IRUBS AND TREES			
ɔies spp.	Fir	A,B,D,E	Allman 1952; Kufeld and others 1973; Steinhoff 1978
cer spp.	Maple	A,B,C,E	Cronquist and others 1972; Kufeld and others 1973; Ream 1963
nelanchier spp.	Serviceberry	A,B,C,D	Kufeld and others 1973; Ream 1963; Steinhoff 1978; Wells 1960
temisia spp.	Sagebrush	A,B,C,D,E	Forsling and Storm 1929; Kufeld and others 1973; Ream 1963; Steinhoff 1978; Wells 1960
eanothus spp.	Snowbush	A,B,C,D,E	Kufeld and others 1973; Patton 1969; Ream 1963; Steinhoff 1978; Wells 1960
ercocarpus spp.	Mountain-mahogany	A,B,C,D,E	Kufeld and others 1973; Ream 1963; Steinhoff 1978; Wells 1960
niperus spp.	Juniper	A,B,C,D,E	Allman 1952; Kufeld and others 1973; Steinhoff 1978; Wells 1960
ahonia repens	Oregon-grape	A,B,D	Cronquist and others 1972; Ream 1963; Steinhoff 1978
ıchistima myrsinites	Mountain lover	A,B,C,D,E	Dixon 1935; Kufeld and others 1973; Ream 1963; Steinhoff 1978
ıysocarpus malvaceus	Ninebark	A	Ream 1963
nus ponderosa	Ponderosa pine	B,C,D	Cronquist and others 1972; Steinhoff 1978; Wells 1960
ɔpulus tremuloides	Quaking aspen	A,B,C,E	Hayward 1948; Kufeld and others 1973; Patton 1969; Steinhoff 1978
unus virginiana	Chokecherry	A,B,C,E	Dixon 1935; Kufeld and others 1973; Ream 1963; Steinhoff 1978
ırshia tridentata	Bitterbrush	A,B,C,D	Cronquist and others 1972; Kufeld and others 1973; Ream 1963; Steinhoff 1978
ɔsa spp.	Wild rose	A,B,D,E	Kufeld and others 1973; Ream 1963; Steinhoff 1978
ımbucus spp.	Elderberry	A,D	Allman 1952; Cronquist and others 1972
mphoricarpos spp.	Snowberry	A,B,C,D,E	Cronquist and others 1972; Kufeld and others 1973;Ream 1963; Steinhoff 1978
)RBS			
hillea millefolium	Yarrow	A,B,C,E	Kufeld and others 1973; Patton 1969
ter spp.	Aster	A,B,C,D,E	Forsling and Storm 1929; Kufeld and others 1973; Ream 1963; Steinhoff 1978
lsamorhiza spp.	Balsamroot	A,B,C	Forsling and Storm 1929; Kufeld and others 1973; Ream 1963
rsium spp.	Thistle	A,B,D	Kufeld and others 1973; Ream 1963
geron spp.	Fleabane	A,B,C,D	Allman 1952; Cronquist and others 1972; Steinhoff 1978
ogonum spp.	Buckwheat	A,B,C,D,E	Cronquist and others 1972; Kufeld and others 1973; Ream 1963; Steinhoff 1978

Table 2.—(Con.)

Species	Common name	Zone[1]	Source of information
Hydrophyllum capitatum	Waterleaf	A,B	Kufeld and others 1973; Ream 1963
Lathyrus spp.	Peavine	A,B,D	Kufeld and others 1973; Ream 1963; Steinhoff 1978
Lupinus spp.	Lupine	A,B,C,D	Cronquist and others 1972; Forsling and Storm 1929; Ream 1963
Polygonum spp.	Knotweed	A,B,C,D	Forsling and Storm 1929; Kufeld and others 1973; Ream 1963
Senecio spp.	Groundsel	A,B,D	Kufeld and others 1973; Ream 1963
Solidago spp.	Goldenrod	A,B,C,D	Allman 1952; Cronquist and others 1972; Steinhoff 1978
Taraxacum spp.	Dandelion	A,B,D,E	Kufeld and others 1973; Ream 1963; Steinhoff 1978
Tragopogon spp.	Goatsbeard	A,B,D	Kufeld and others 1973; Ream 1963
Viola spp.	Violet	A,B,D	Allman 1952; Kufeld and others 1973
Wyethia amplexicaulis	Mulesears	A,B,C	Cronquist and others 1972; Ream 1963; Steinhoff 1978
GRAMINOIDS			
Agropyron spp.	Wheatgrass	A,B,C,D	Dixon 1935; Kufeld and others 1973; Ream 1963; Steinhoff 1978
Bromus spp.	Bromegrass	A,B,D	Kufeld and others 1973; Ream 1963; Steinhoff 1978
Carex spp.	Sedge	A,B	Ream 1963; Steinhoff 1978
Elymus spp.	Wildrye	A,B,D	Kufeld and others 1973; Ream 1963; Steinhoff 1978
Festuca spp.	Fescue	B,C,D,E	Forsling and Storm 1929; Kufeld and others 1973; Steinhoff 1978
Koeleria cristata	Junegrass	A,B,D	Kufeld and others 1973; McKell 1950; Steinhoff 1978
Melica spp.	Oniongrass	A,E	Kufeld and others 1973; Steinhoff 1978
Poa spp.	Bluegrass	A,B,C,D,E	Forsling and Storm 1929; Kufeld and others 1973; Ream 1963; Steinhoff 1978
Stipa spp.	Needlegrass	A,B,C,D	Cronquist and others 1972; Kufeld and others 1973; Ream 1963; Steinhoff 1978

[1]A = central Utah, B = Colorado, C = southern Utah, D = Arizona, E = New Mexico.

able 3.—Animals associated with Gambel oak in various parts of its range. A source of information concerning species occurrence in a given area is reported. (To save space, only one reference is cited to establish an animal's occurrence in an area.)

Species	Common name	Zone[1]	Source of information
IRDS			
lphelocoma coerulescens	Scrub jay	A,B,D	Brotherson and others 1981; Hayward 1948; Steinhoff 1978
quila chrysaetos	Golden eagle	A,B	Hayward 1948; Steinhoff 1978
'onasa umbellus	Blue grouse	A,B	Hayward 1948; Steinhoff 1978
'ubo virginianus	Great horned owl	A,C	USDA Forest Service 1983
'uteo jamaicensis	Red-tailed hawk	A,B	Hayward 1948; Steinhoff 1978
. regalis	Ferruginous hawk	A,B	Hayward 1948; Steinhoff 1978
'athartes aura	Turkey vulture	A,B,D	Brotherson and others 1981; Hayward 1948; Steinhoff 1978
'hlorura chlorura	Green-tailed towhee	A,B	Hayward 1948; Steinhoff 1978
'olaptes cafer	Common flicker	A,C	USDA Forest Service 1983
'olumba fasciata	Band-tailed pigeon	B,D,E	Lamb 1971; Reynolds and others 1970; Steinhoff 1978
ontopus sordidulus	Western wood pewee	A,C	USDA Forest Service 1983
orvus brachyrhynchos	Crow	A,B	Hayward 1948; Steinhoff 1978
yanocitta stelleri	Steller's jay	A,B	Hayward 1948; Steinhoff 1978
endragapus obscurus	Blue grouse	A	Hayward 1948
mpidonax spp.	Flycatchers	A,B,D	Brotherson and others 1981; Hayward 1948; Steinhoff 1978
alco mexicanus	Prairie falcon	A	Hayward 1948
. sparverius	American kestrel	A	Hayward 1948
ylocichla guttata	Hermit thrush	A,B,D	Brotherson and others 1981; Hayward 1948; Steinhoff 1978
unco spp.	Junco	A,B	Hayward 1948; Steinhoff 1978
ophortyx californicus	California quail	A,E	Hayward 1948; Lamb 1971
'eleagris gallopavo	Turkey	D,E	Lamb 1971; Reynolds and others 1970
arus gambeli	Mountain chickadee	A,B,D	Brotherson and others 1981; Hayward 1948; Lamb 1971
asser domesticus	House sparrow	A	Marti 1977
asserina amoena	Luzuli bunting	A,B	Hayward 1948; Steinhoff 1978
halaenoptilus nuttallii	Nuttall poorwill	A,B	Hayward 1948, Steinhoff 1978
hasianus colchicus	Ringneck pheasant	A	Hayward 1948
'ica pica	Magpie	A,B	Hayward 1948; Steinhoff 1978
'icoides villosus	Hairy woodpecker	B,D	Steinhoff 1978; Lamb 1971
'ipilo erythrophthalmus	Rufous-sided towhee	A,C	USDA Forest Service 1983
alpinctes obsoletus	Rock wren	A,B	Hayward 1948; Steinhoff 1978
elasphorus rufus	Rufous hummingbird	A,C	USDA Forest Service 1983
'ali currucoides	Mountain bluebird	A,C	USDA Forest Service 1983
'tta carolinensis	White-breasted nuthatch	B,D	Steinhoff 1978; Lamb 1971

Table 3.—(Con.)

Species	Common name	Zone[1]	Source of information
Spinus spp.	Goldfinch	A,B	Hayward 1948; Steinhoff 1978
Spizella spp.	Sparrow	A,B	Hayward 1948; Steinhoff 1978
Sturnella neglecta	Meadowlark	A,B	Hayward 1948; Steinhoff 1978
Troglodytes aedon	House wren	A,B,D	Brotherson and others 1981; Hayward 1948; Steinhoff 1978
Turdus migratorius	Robin	A,B,D	Brotherson and others 1981; Hayward 1948; Steinhoff 1978
Vermivora spp.	Warblers	A,B,D	Brotherson and others 1981; Hayward 1948; Steinhoff 1978
Vireo gilvus	Warbling vireo	A,B,D	Brotherson and others 1981; Hayward 1948; Steinhoff 1978
Zenaidura macroura	Mourning dove	A,B,D	Brotherson and others 1981; Hayward 1948; Steinhoff 1978
MAMMALS			
Canis latrans	Coyote	A,B,E	Hayward 1948; Lamb 1971; Steinhoff 1981
Cervus canadensis	Elk	A,B,D,E	Hayward 1948; Lamb 1971; Reynolds and others 1970; Steinhoff 1978
Citellus spp.	Ground squirrel	A,B,E	Hayward 1948; Lamb 1971; Steinhoff 1978
Dicotyles tajacu	Javelina	D,E	Lamb 1971
Erethizon dorsatum	Porcupine	A,C	USDA Forest Service 1983
Eutamias spp.	Chipmunk	A,B	Hayward 1948; Steinhoff 1978
Lepus spp.	Jackrabbit	A,B	Hayward 1948; Steinhoff 1978
Lepus americanus	Snowshoe hare	A,B	Hayward 1948; Steinhoff 1978
Lynx rufus	Bobcat	A,B	Hayward 1948; Steinhoff 1978
Marmota flaviventris	Marmot	A,B	Hayward 1948; Steinhoff 1978
Mephitis occidentalis	Striped skunk	A,B	Hayward 1948; Steinhoff 1978
Microtus spp.	Meadow mouse	A	Hayward 1948
Mustela spp.	Weasel	A	Hayward 1948
Odocoileus hemionus	Mule deer	A,B,D,E	Hayward 1948; Kufeld 1970a
O. virginianus	White-tailed deer	D,C	Lamb 1971; Patton 1969
Perognathus parvus	Pocket mouse	A	Hayward 1948
Peromyscus spp.	Mice	A,B	Hayward 1948; Steinhoff 1978
Sciurus aberti	Abert squirrel	B,D,E	Reynolds and others 1970; Steinhoff 1978
Spilogale gracilis	Spotted skunk	A,B	Hayward 1948; Steinhoff 1978
Sylvilagus nuttallii	Cottontail rabbit	A,B,D,E	Hayward 1948; Patton 1969; Reynolds and others 1970; Steinhoff 1978
Taxidea taxus	Badger	A,B	Hayward 1948; Steinhoff 1978
Ursus americanus	Black bear	B,D,E	Lamb 1971; Patton 1969; Steinhoff 1978

[1]A = central Utah, B = Colorado, C = southern Utah, D = Arizona, E = New Mexico.

Steinhoff shows, in a general way, how the kinds or amounts of various biological products can be expected to vary among these seven associations. General characteristics of the seven associations recognized by Steinhoff within the Gambel oak type of southwestern Colorado are summarized in table 4.

The three associations that contain ponderosa pine (table 4) produce considerable tree biomass and relatively little herbaceous material. Ponderosa pine-oak stands tend to have primarily small oak, but oak becomes quite large in all other associations except the pinyon-juniper-oak type. The last type also has the least well-developed understory vegetation of the seven association types recognized by Steinhoff (1978). Herbaceous understory appears to be best developed in the oak—serviceberry—Oregon-grape type, but oak-serviceberry and pure oak associations also have large populations of herbaceous species (table 4).

As a starting point, Steinhoff's (1978) associations appear to be worthy of recognition throughout the range of Gambel oak. The system can and should be further refined, however.

Successional Dynamics

Successional trends in Gambel oak communities may lead to suppression of oak by canyon maple (*Acer grandidentatum*), white fir (*Abies concolor*), ponderosa pine (*Pinus ponderosa*), Rocky Mountain juniper (*Juniperus scopulorum*), or pinyon pine (*P. edulis*) (Dixon 1935; Hayward 1948; McKell 1950; Allman 1953; Christensen 1950, 1958; Nixon and Christensen 1959; Nixon 1961, 1967; Cronquist and others 1972; Steinhoff 1978; Floyd 1982). Dixon (1935) suggested that in most areas oak is an ecological equivalent to ponderosa pine, but in such areas as the Aquarius Plateau of central Utah, it appears to be pioneer to the pines. Floyd (1982) concluded that pinyon was capable of invading and becoming the dominant tree on oak sites near Dolores, Colorado. Brown (1958) considered oak to be a climax species, but Cronquist and others (1972) suggested that it is subclimax to ponderosa pine. Floyd's (1982) work suggests that oak is also subclimax to pinyon, at least locally in southwestern Colorado. In all probability, oak forms climax cover on some sites, but on many others there is unequivocal evidence that it is seral. Several authors have presented evidence that maple is invading oak stands and will eventually replace them (Allman 1952, 1953; Nixon and Christensen 1959; Nixon 1961, 1967; Eastmond 1968; Eastmond and Christensen 1968). Christensen (1964) believed that oak stands on steep, north-facing slopes in Provo Canyon, Utah, were moving toward dominance by a mixture of white fir and Douglas-fir.

Allman (1952, 1953) and McKell (1950) concluded that fire killed oak stems, but not roots and rhizomes. Oak sprouts prolifically after fire, producing a denser stand than was present before burning (McKell 1950; Allman 1952, 1953). Both Allman and McKell considered that after 18 years an oak stand would have essentially the same structure as before the fire. Brown (1958) and McKell (1950) show that oak thickets are dense when young but thin out as the stands mature. Hallisey and Wood (1976), working in Pennsylvania, reported that burning did not eliminate plant species initially existing in oak stands nor enhance invasion of new species. In Utah, however, late successional woody species appear to be more vulnerable to fire than oak itself. Kunzler and others (1981) also show that even in early and mid-successional stages of oak stands in central Utah, fire

Table 4.—Comparative plant density and species richness data for seven Gambel oak association types in Colorado; all data are from Steinhoff (1978)

Characteristic	PPO[1]	PO	PJO	PJPO	OSO	OS	O
	Number of individuals/0.1 acre						
Ponderosa pine stems							
Over 9.0 inches d.b.h.[2]	92	29	0	37	0	0	0
1 to 9 inches d.b.h.	96	39	0	10	0	0	0
Gambel oak stems							
Over 4.0 inches d.b.h.	2	2	1	10	6	4	14
1 to 4 inches d.b.h.	14	42	15	57	45	39	41
Pinyon stems	0	0	139	3	0	1	0
Juniper stems	4	2	84	3	0	1	0
Small shrubs	324	243	145	433	554	483	267
Forbs	180	176	27	90	212	229	250
Graminoids	81	110	60	43	288	194	164
	Number of species/0.1 acre[3]						
Shrubs	6	8	6	5	8	8	5
Forbs	15	16	13	5	17	20	20
Graminoids	10	9	8	3	11	11	9
TOTAL	31	33	27	13	36	39	34

[1]Association abbreviations represent the following: PPO = dense ponderosa pine-oak; PO = open ponderosa pine-oak; PJO = pinyon-juniper-oak; PJPO = pinyon-juniper-ponderosa pine-oak; OSO = oak—serviceberry—Oregon-grape; OS = oak-serviceberry; and O = pure oak.

[2]d.b.h. = diameter at breast height.

[3]Represents only the nontree species that are listed in Steinhoff (1978); all trees and oak itself are omitted.

exerts a conspicuous influence on plant composition in the herb layer; annual species increase after fire while several perennial herbs decrease. Nevertheless, the compositional impacts of fire in the oak type of Utah appear to disappear in less than 20 years (McKell 1950).

In the southern portion of its range, Gambel oak often forms open stands of small, competition-suppressed plants under ponderosa pine forest canopies. Should the pine be removed from such stands by fire or logging, oak often becomes dominant (Pearl 1965; Dick-Peddie and Moir 1970). Reestablishment of pine on sites thus stocked with oak is difficult. Herman Ball (cited in Steinhoff 1981) estimated that over half the area potentially available for commercial growth of ponderosa pine had been taken over by oak on the San Juan National Forest of Colorado. Steinhoff (1981) believed that repeated light fires would reduce oak vigor and permit ponderosa pine reproduction to regain control of such sites. Hot fires eliminated pine and left oak in control of the site.

Studies are rare in which observers have recorded community traits where Gambel oak has been displaced as the stand dominant by any other woody species. Eastmond (1968) summarized his own observations and those of two others (Allman 1952; Nixon 1961, 1967) of an oak stand in central Utah that was being invaded by canyon maple. One can also draw some inferences about likely changes associated with natural succession from analyses of stands dominated by oak or a potential replacement species on comparable sites and in the same geographic area. Table 5 data are an attempt to predict the direction of change in several community characteristics as oak is displaced by ponderosa pine, white fir, or canyon maple. Inferences for ponderosa pine are based on Steinhoff's (1978) data from southwestern Colorado. Conclusions about changes associated with displacement of oak by white fir were drawn from analysis of data presented by Ream (1963) and unpublished data of our own. Consequences of canyon maple's invasion of oak stands were inferred from studies by Ream (1963), Eastmond (1968), and Kunzler and others (1981).

Available data suggest that many changes resulting from natural succession in Gambel oak stands will be the same whether the invading species is ponderosa pine, white fir, or canyon maple (table 5). In all cases, understory production will probably decline and the new canopy dominant will be less palatable to deer than oak (Kufeld and others 1973). Likewise, all three of the invading species are likely to produce more marketable lumber than oak. Reduced production in the understory is expected because the replacement species are either evergreens (the conifers) that continuously shade the forest floor or, in the case of maple, leaf out several days before oak (Eastmond 1968). The downward trend in understory production will also be abetted by accumulation of deep litter layers under both conifer species. Maple leafs out earlier than oak and at a time when soil water is readily available and temperature and light conditions are ideal for understory growth if there is little or no canopy cover. This leads us to conclude that understory production would decline as oak stands are invaded by maple. Greater productivity of the invading trees is at least partially attributable to the fact that they bear evergreen foliage or (in the case of maple) foliage on more days when soil moisture is abundant. Although oak leaves remain green longer than maple leaves in the fall, that is usually a period when soils are dry.

The data suggest that composition in the understory (relative forage production attributable to shrubs, grasses, and forbs) will probably show slight increases i forbs and declines in shrubs and grasses (table 5). In an event, large changes in composition are not likely. Floristi richness in the understory is expected to decline where conifers displace oak, but trends in richness may be upward when the invading species is maple (Eastmond 1968; Ream 1963).

Evergreen foliage and a tendency to retain basal branches for long periods make stands with conifers superior escape cover for large animals. Maple may prove to be poorer escape cover than oak, because of early defoliation in the autumn and a strong tendency t form dense, self-pruning stands. Resinous foliage and heavy litter layers will render stands invaded by conifer progressively more fire prone. Maple stands, however,

Table 5.—Likely changes in the plant community as Gambel oak is displaced by ponderosa pine, white fir, or canyon maple in natural successions. Changes ar inferred from literature descriptions of actual sites in process of succession or from comparison of descriptions of stands on comparable sites but dominated by oak or the displacing species. Changes are shown as increases (+), decreases (–), or no change (0) in the factor in question during succession. Apparent trends that are question ble for any reason are noted by a question mark.

Factor	Forest type displacing oa Ponderosa pine[1]	 White fir[2]	 Canyo maple
Understory composition (percent):			
Shrubs	0	–	–
Graminoids	–	–	0?
Forbs	0	+	+
Total understory production	–	–	–
Floristic richness of understory	0	0	+?5
Palatability of displacing species[4]	–	–	–
Value as escape cover for deer	+	+	–
Lumber production	+	+	+?6
Fire proneness	+	+	–

[1]Inferred from comparison of averages for Steinhoff's (1978) pon derosa pine–oak associations.
[2]From Ream (1963).
[3]Based on Eastmond (1968) and Kunzler and others (1981).
[4]Based on use by deer in all seasons as gleaned from literature by Kufeld and others (1973).
[5]Eastmond (1968) shows a large increase in number of understo species per quadrat over an 18-year period in which maple rapidly creased in a stand originally dominated by oak, but the stand had been heavily grazed prior to the 18-year period and was ungrazed during that period. Thus, separation of grazing and successional processes as causes for the increase in floristic richness is not possible.
[6]Based on rates of increase in oak and maple basal area in Eas mond's (1968) study and observations by Christensen (1958).

will probably be less prone to burn than the original oak stands, because maple foliage decomposes more rapidly than that of either oak or the conifers (personal observations). Reduced growth in the understory of maple will also reduce the supply of potential fuel.

Successions in which oak is invaded and displaced as the dominant by ponderosa pine are apparently common in Arizona, New Mexico, southwestern Colorado, and southeastern Utah in the upper half of the altitudinal range of oak (Dixon 1935). Canyon maple probably most commonly invades oak in Utah and northern Arizona, but that species is apparently present only locally on the western slope of the Rockies in Colorado (Little 1976). Canyon maple invades first along streams, bases of slopes, and intermittent drainages throughout all but the highest elevation stands of oak. During the last quarter century, canyon maple has appeared on upland sites between drainages in central and northern Utah; there maple is now overtopping and gradually displacing oak. Apparently, canyon maple is adapted to a broader array of sites than prior workers believed. Most general descriptions of the ecology of the species have described it as growing on banks of streams or along water courses (Tidestrom 1925; Sargent 1926; Davis 1952). Ecological descriptions of the vegetation of the Gambel oak zone of Utah written in the 1925-45 period make no mention of oak maple (Sampson 1925; Dixon 1935; Cottam and Evans 1945). Considering the showiness of maple in autumn color, its omission from previous descriptions of the oak zone is unexpected and suggests that the current prominence of maple on open slopes in the foothills of Utah mountains is a comparatively recent occurrence.

We have no fully satisfactory explanation for the recent surge in prominence of maple in the oak zone of this region. One is tempted to explain the observations in terms of better control of brush fires in the oak zone during the past half century. Fires could be expected to be more frequent and more intense on drier sites. It is known, however, that maple sprouts at least occasionally after fire in central Utah (personal observations). Unfortunately, there appear to be no observations on either the relative frequency of fire along drainage ways and on adjacent open slopes in our area nor on the relative frequency and vigor of maple sprouting after fire on such contrasting sites.

White fir invasions are to be expected only on cooler sites in the upper half of the elevational range of oak (Lull and Ellison 1950). On some such sites, canyon maple may precede white fir as a seral species, thus producing a longer and more complicated successional sequence. Portions of the stand studied by Eastmond (1968) had shifted from oak to maple dominance during the 19 years of study, but the steady increase in frequency of white fir seedlings in the understory suggests that another cycle of displacement of the canopy dominant may lie ahead. Eastmond believed that the white fir reproduction would not persist on the site, but he presented no evidence of fir mortality.

Rocky Mountain juniper is often a persistent member of ponderosa stands and reproduces with some regularity there (personal communication, Hayle Buchanan). In central Utah and northwestern Colorado, ponderosa pine is essentially absent, being found only occasionally and then only as scattered individuals or small groves. In that area, Rocky Mountain juniper is still present and may become an important invader of oak stands (Lull and Ellison 1950). No published reports of studies of such successional situations were found, however.

Steinhoff (1978) has evaluated the effects of the successional process in Colorado oak associations on associated animal species. His conclusions are summarized in table 6. It would appear that Steinhoff's conclusions are also useful in Utah and Arizona, but he apparently did not study oak stands where the climax cover was dominated by canyon maple or white fir. Because both canyon maple and white fir often appear to displace Gambel oak in natural successions in Utah and Arizona, there is a need to evaluate the consequences of succession in respect to plant composition (in both the overstory and understory) in stands being invaded by those species. The impacts of such successional processes on associated animals must also be determined.

Table 6.—Distribution of selected animals that are at least seasonally influenced by a Gambel oak association. Three widely divergent plant associations in which Gambel oak is important are considered here. The occurrence of each animal species in each plant association is noted. The successional stage that an animal prefers in each plant association is also reported. The tolerance of each animal to severe disturbance of the community by fire, cutting, grazing, or herbicide treatment is estimated. Contents of this table are drawn from a report by Steinhoff (1978), which is based on the author's experience in southwestern Colorado.

Dependent species	Zone of occurrence[1]			Seral stage of best development[2]	Fire	Disturbance[3]		
	PPO	OSO	PJO			Cutting	Grazing	Herbicic
DEPENDENT TAXA								
Aphelocoma spp. (jays)		x	x	L	T[3]	T	T	—
Chlorura chlorura (green-tailed towhee)	x	x	x	NP	T	T	T	—
Cyanocitta stelleri (Steller's jay)	x	x	x	L	T	T	—	—
Empidonax oberholseri (flycatcher)	x	x		E-M	T	T	T	T
Meleagris gallopavo (turkey)	x	x		NP	I	I	I	—
Sciurus aberti (Abert squirrel)	x			M-L	I	I	—	—
INFLUENCED TAXA								
Bonasa umbellus (ruffed grouse)		x		M-L	—	—	—	—
Buteo regalis (ferruginous hawk)		x	x	L	I	I	I	I
Columbia fasciata (band-tailed pigeon)			x	L	—	—	—	—
Empidonax wrightii (flycatcher)		x	x	L	T	—	T	—
Hylocichla guttata (hermit thrush)	x			M	I	I	I	—
Junco spp. (junco)	x			M	T	T	—	—
Passerina amoena (lazuli bunting)		x		M	T	T	T	—
Phalaenoptilus nuttallii (poorwill)		x		M	T	T	T	T
Pica pica (magpie)		x		L	—	T	—	—
Salpinctes obsoletus (rock wren)			x	M*	—	T	—	—
Spinus spp. (goldfinch)	x	x		L	I	I	—	I
Spizella passerina (sparrow)	x			M-L	T	T	—	—
Vermivora celata (warbler)	x			L	T	T	—	—
Vermivora virginiae (warbler)	x	x	x	L	T	—	I	—
Zenaidura macroura (mourning dove)	x	x	x	E	T	T	T	T
Cervus canadensis (elk)	x	x	x	M	T	T	I	T
Mustela erminea (ermine)	x	x	x	M*	T	T	—	T
Mustela frenata (weasel)	x	x		M*	T	T	—	T
Odocoileus hemionus (mule deer)	x	x	x	M	T	T	T	T
Sylvilagus nuttallii (cottontail rabbit)	x	x	x	M	T	T	—	T
Ursus americanus (black bear)	x			M	T	T	—	T

[1]Zones of occurrence are: PPO = dense ponderosa pine-oak; OSO = oak—serviceberry—Oregon-grape; PJO = pinyon-juniper-oak.
[2]Seral stages are: E = early; M = medium; L = late; * = slight preference for this zone; NP = no preference.
[3]Animal tolerance classes are: T = tolerant; I = intolerant; — = more data needed.

USES AND VALUES

Forage Production

Forage production in Gambel oak communities is controlled by several variables including precipitation (table 7), soil depth and fertility (Hutchings and Mason 1970), prior grazing (Thomas 1970), and oak canopy conditions (Frischknecht and Plummer 1955; Moinat 1956; Jefferies 1965a; Astatke 1967; Marquiss 1972). Workers often report only understory production, but Hutchings and Mason (1970) showed that the oak canopy can produce at least as much and often more annual growth than the understory. They showed that annual plant production in the canopy may range from 0.4 to 1.6 lb/yd^2 (0.48 to 0.87 kg/m^2) depending upon precipitation and soils at the site. Steinhoff (1981) noted that herbaceous production was several times greater in openings than under the canopies of oak thickets at the edge of the opening.

Shrubs normally dominate the forage production of all oak-dominated communities (Thomas 1970; Steinhoff 1978), but some oak understories are dominated by sedges (Sweeney and Steinhoff 1976). Forbs always seem to contribute less than 50 percent of the understory forage production (Moinat 1956; Jefferies 1965a; Thomas 1970). Grasses do well when seeded or released from competition on sites where oak dominance has been reduced by fire or mechanical treatments (Frischknecht and Plummer 1955; Plummer and others 1968; Vallentine and Schwendiman 1973; Marquiss 1973).

Chapline (1919) found Gambel oak foliage to be of moderately high palatability for goats with preference being highest in the summer. Nastis and Malechek (1981) noted that high tannin levels in oak tissue reduced utilization of protein in that tissue when consumed by goats. The effect was apparently the result of a chemical reaction in the digestive tract between tissue tannins and proteins, rendering the protein partially unavailable to the animal.

Throughout its range, Gambel oak appears to increase slowly in the face of moderately heavy grazing, while associated herbaceous species decline (Price 1938; Costello and Turner 1941; Ellison 1960; Thomas 1970) and recover slowly even in the absence of grazing animals (Thomas 1970). Shepherd (1971) showed that Gambel oak in southwestern Colorado declined only moderately in vigor after having 60 percent of its current annual growth removed for 12 consecutive years. Such tolerance of defoliation coupled with relatively low palatability to sheep and cattle probably explains why the species has increased in abundance throughout its range during the past century.

Price (1938), Frischknecht and Plummer (1955), and Plummer and others (1970) showed that the oak zone has good potential for range improvement through reseeding. Vallentine and Schwendiman (1973) and Marquiss (1972) demonstrated that native grasses responded with markedly greater production when the oak canopy was removed with herbicides. Price (1938) considered

Table 7.—Annual aboveground production in Gambel oak stands

Location	Annual precipitation		Annual production[1]		Comments	Source of information
	Inches	*cm*	*Lb/acre*	*kg/ha*		
Southern Utah	14–16	36–41	1,075	1 205	Under and overstory included	Mason and others (1967)
Western Colorado	15	38	346	388	Understory only	Brown (1958)
Utah	Several sites		535–3,185	600–3 569	Oak overstory only	Hutchings and Mason (1970)
Southwestern Colorado	18.5	47	189	212	Understory (grazed)	Jefferies (1965a)
			319	357	Understory (ungrazed)	
			253	285	Open parks (grazed)	
Southwestern Colorado			394	442	Open parks (ungrazed)	Marquiss (1972)
			585	656	Understory and overstory (no herbicide)	
			1,061	1 189	Understory (overstory removed by herbicide)	
Northern Colorado	18.5	47	404	453	Understory (grazed)	Moinat (1956)
			873	978	Understory (ungrazed)	
			771	864	Open parks (grazed)	
			1,371	1 536	Open parks (ungrazed)	
Central Utah	22.5	57	519–627	582–703	Understory only	Thomas (1970)
Central Utah	22.8	58	1,400	1 569	Reseeded oak-sage type (grazed)	Frischknecht and Plummer (1955)
			2,231	2 500	Reseeded oak-sage type (ungrazed)	

[1]Includes only aboveground growth of herbs; when overstory is included, wood of current-year twigs is included, but annual wood accretion in stems older than 1 year is ignored.

that reseeding could increase carrying capacity in oak from 367 to 933 percent. Marquiss (1972) reported almost 60 percent more beef production per unit area following removal of the oak overstory with herbicides in southwestern Colorado. Plummer and others (1970) considered that seeding adapted grasses, such as smooth brome, intermediate wheatgrass, or fairway crested wheatgrass could markedly slow the recovery of oak after control by chaining or fire. They found that grasses seeded under oak treated to reduce dominance became fully established in 3 or 4 years; grasses seeded under untreated oak took from 6 to 10 years to become fully established. Additional research on seeding mixtures, time needed for herbaceous species to become established, and effect of competing herbs on oak recovery is needed.

The slow recovery of herbs associated with oak even in the absence of domestic or big game grazers can be observed in numerous fenced study plots throughout the range of Gambel oak. Laycock (1969) documents the location of 39 grazing exclosures or natural areas in oak in Utah alone. All exclosures seem to show limited recovery of understory herbs.

Wildlife Use

Oakbrush communities provide valuable big game winter range for wildlife in Arizona (Russo 1964), Utah (Plummer and others 1968), and Colorado (Steinhoff 1978). Perry (1980) estimated that Gambel oak contributed as much as 75 percent of the available forage in winter on foothills of the Wasatch Mountains in Utah County, Utah. Because big game populations are often limited by the availability and conditon of their winter range (Kufeld 1970a), oakbrush ranges have a significant effect on big game ecology. Russo (1964) suggested that oakbrush ranges are used heavily in winters with heavy snowfall, but lightly in light winters. Experience in central Utah has shown that decades of wildfire suppression have pushed much of the browse of Gambel oak out of reach of wintering big game. Opening of "browseways" and small clearings with chainsaws in dense, decadent oak stands resulted in a threefold increase in usable forage and a fourteenfold increase in deer use (Perry 1981).

In northern Utah, Smith (1950, 1953) and Smith and Hubbard (1954) studied feeding habits of deer on native browse and herbaceous forage species. Among the browse species, Gambel oak ranked from seventh (Smith 1950) to first (Smith and Hubbard 1954) in terms of the amounts consumed and the amount of time big game spent in stands of each species. Smith (1952) listed Gambel oak among the top 10 browse species in the Fishlake National Forest. Reynolds and others (1970) listed several wildlife species including deer, elk, turkeys, and squirrels that utilize Gambel oak for browse or mast.

Smith (1949, 1952) reported that the percentage of oak utilized by deer varies with the availability of more favorable browse species. Kufeld (1973) ranked the plant species eaten by elk as highly valuable or least valuable; he ranked Gambel oak as highly valuable for winter and spring. Allman (1952) and Hayward (1948) also considered oak an important cover for deer.

Many researchers have reported an increase in use by deer and elk when areas are treated by fire, herbicides, or mechanical means to control Gambel oak (Price 1938; Anon. 1966; Patton 1969; and Plummer and others 1970). Steinhoff (1978) listed many species of wildlife found in oak associations (table 6) and rated them as tolerant or intolerant to several different types of treatments which will be discussed in more detail later in this review.

Some of the more common bird and mammal species found within the oakbrush zone are listed in table 3. Brotherson and others (1981) described the bird community of oak stands in Navajo National Monument, northern Arizona. They contrasted the avian community of oak stands with that of several other plant communities in the Monument and found many more bird species associated with oak on mesic (riparian edge) than on xeric (as in juniper-oak stands) sites. The scrub jay, white-breasted nuthatch, common flicker, hairy woodpecker, mountain chickadee, and rufous-sided towhee were regularly observed in oak stands. The oak community had greater richness of bird species than pinyon-juniper woodlands adjacent to it. Black (1983) demonstrated that house wren populations in the ponderosa pine-Gambel oak stands of southeastern Utah could be significantly enlarged by increasing the number of cavities for nesting. Most Gambel oak stands have few trees with natural cavities. Preservation of larger snag trees of any species on oak-dominated sites would probably encourage larger wren populations on more mesic sites and larger bluebird populations on drier sites where oak grades into pinyon-juniper woodland (Brotherson and others 1981; Black 1983).

In northern Utah, Marti (1977) found blue-gray gnatcatchers (*Polioptila caerulea*), black-headed grosbeaks (*Pheucticus melanocephalus*), Lazuli buntings, and rufous-sided towhees to be the most common nesting birds in oakbrush stands. Only six bird species were permanent residents at Marti's site; these were California quail, ring-neck pheasant, scrub jay, black-billed magpie, black-capped chickadee (*Parus atricapillus*), and rufous-sided towhee.

Domestic Animal Use

Most studies indicate that cattle and sheep utilize oak only after the more desirable plant species are diminished. Goats, however, readily consume Gambel oak and do well on the mature foliage provided the diet contains other forage that is nutritious and lower in tannin content than oak (Davis and others 1975; Nastis and Malechek 1981). Nastis and Malechek (1981) found that 50 to 75 percent of the diet of Spanish goats could come from mature oak browse without impairing digestibility of dietary protein or the amount of metabolizable energy in the forage.

Herbaceous forage production can be up to twice as great in clearings between clumps of oak as it is beneath oak canopies (table 7) (Forsling and Storm 1929; Moinat 1956; Ellison 1960; Thomas 1970). Treatments that reduce dominance of oak can increase herbaceous forage and its accessibility to domestic animals (Marquiss 1972; Moinat 1956; Price 1938).

Shepherd (1971) suggested that oak can be safely utilized until about 60 percent of the current annual growth is consumed. If the objective is to reduce plant vigor, utilization must be 80 to 100 percent.

Watershed

Although several studies treat the water relations of Gambel oak as a species (Tew 1966, 1967, 1969; Marquiss 1972), few consider the yield and hydrodynamics of watersheds where Gambel oak is a major species. Croft (1944) documented the water relations of Whipple Basin in the northern Wasatch Mountains of Utah, a watershed dominated by Gambel oak. He showed that precipitation on Whipple drainage averaged about 31 inches (78.7 cm); total annual discharge was equivalent to approximately 10.5 inches (26.7 cm) per unit surface area. Accordingly, that watershed released about one-third of the annual precipitation as surface runoff. Because average elevation on the watershed was about 7,500 ft (2 286 m), the area was above average elevation for the Gambel oakbrush vegetational type and probably received more precipitation than the average oakbrush stand. As Branson and others (1981) showed, watershed runoff as a proportion of total precipitation is closely correlated with total amount of precipitation. Accordingly, we would expect most oakbrush watersheds to generate less surface flow than Whipple drainage. Dortignac (1956) does not consider Gambel oak in his review of Southwestern watersheds, but he lists ponderosa pine which would occur at about the same elevation as oakbrush in the area studied. He found that the average ponderosa pine-dominated watershed would yield about 17 percent of the annual precipitation as runoff. Because a larger portion of the annual precipitation at Whipple drainage would accumulate as winter snow, we would expect a greater proportion of it to appear as streamflow in Utah than in the Southwest, but the water yield efficiency observed by Croft (1944) for Whipple drainage is probably greater than could be expected from most Gambel oak-dominated watersheds.

Grover and others (1970a) developed a theoretical model for predicting water yield increases when deep-rooted woody species are replaced by herbaceous cover in central Utah. Their model predicted that replacement of Gambel oak with herbs would increase water yield by about 0.9 to 5.4 inches (2.3 to 13.7 cm) per year as one moved from the lower to the upper elevational limits of the oakbrush zone in Ephraim Canyon, Sanpete County, Utah.

Tew (1967, 1969) concluded that removal of oakbrush from central Utah watersheds might release as much as an additional 3.0 inches (7.6 cm) of runoff per unit area. Without control of sprouting, however, he concluded that the gains would be lost again in 3 years or less. Reanalysis of Marquiss' (1972) data suggests that removal of oak from southwestern Colorado rangelands would leave at least 1.4 inches (3.6 cm) of additional water per year in the surface 5 ft (1.5 m) of soil. This estimate is based on percent gravimetric water in five 1.0-ft (30.5-cm) deep soil layers averaged over the entire growing season and across 4 years with an assumption of a dry weight of 1,000 tons per 0.5-ft layer of soil per acre (907.2 tons per 0.15 m layer of soil per ha). The estimate is probably conservative, because the value employed for water use of oak was an average of control and sprout clones and samples were taken from only the surface 5 ft (1.5 m) of soil even though oak is known to draw water from depths greater than that (Tew 1969). Marquiss' (1972) results support those of Tew (1969) in that after four seasons of regrowth, water depletion was essentially equal under control and sprout populations of oak. Parker (1975) concurred that this oak species is a heavy consumer of water. It does, however, provide excellent control over soil erosion on the watersheds that it dominates (Petersen 1954).

Fuel Wood

Although early settlers occasionally used Gambel oak for firewood, the species apparently has never been extensively harvested for use as a fuel. With accelerating costs of fuel oil and natural gas, an increasing number of households in the Intermountain West are using fuel wood for supplemental heating in family dwellings. Schoenfeld (1979) reported that 24,000 permits for fuel wood harvesting in the Wasatch National Forest were issued in 1979. Officials estimated that the fuel wood harvested that year would be equivalent to 24 million board feet of timber from the Wasatch National Forest alone.

Because Gambel oak forms extensive stands at low elevations convenient to large urban centers, it seems likely that the species will be harvested at a more rapid rate in the 1980's than at any other time in history. Although oak often does not form continuous stands on lower elevation, less steep slopes (less than 30 percent) where fuel wood harvests are most likely to occur, the species does produce a significant volume of wood within the areas it occupies. Wagstaff (1984) surveyed seven stands along the Wasatch Front in Utah. Considering only stems over 3 inches (716 cm) d.b.h., Wagstaff found fuel wood volumes ranging from 6.5 to 130 cords per acre (16.1 to 321.2 cords per ha). Because the accessible acreage is large, oak woodlands represent a resource that will probably be much affected by the vigorous public demand for fuel wood. As a consequence, new management problems and opportunities will emerge in the Gambel oak vegetational zone.

Other Uses

Chamberlain (1911) reported that the Goshute Indians, a native race of early historic Utah, prepared the acorns of scrub oak for food in season, but did not preserve them for winter use. The oakbrush community has been used for grazing since the entry of the Mormon pioneers into the Intermountain West (Cottam and Evans 1945). Even before the coming of white settlers, oakbrush communities provided habitat for small mammals (Urquhart 1968), nongame birds (Frost 1947; Marti 1977), big game (Julander 1955; Kufeld 1970a, 1970b, 1973; Kufeld and others 1973), bandtailed pigeons (Pederson 1975), turkeys (Hoffman 1962), javelinas (Knipe 1957), and the Abert squirrel (Keith 1965).

MANAGEMENT

Only a few studies have evaluated management alternatives for the Gambel oak types. For sake of simplicity, management will be considered under three headings: fire, chemical (herbicides), and mechanical (such as chaining, bulldozing, or root plowing). Although complete protection also can be considered as a management technique for improvement of a site for forage production, we consider it impractical because of the long time required to produce favorable results. Brown (1958), Eastmond (1968), Nixon (1961, 1967), and Thomas (1970) indicate that several decades may be required to demonstrate significant changes in the forage base in oak stands undergoing natural recovery. Cottam and Evans (1945) also considered the effects of exclosure of domestic grazers from the oak zone in northern Utah and showed that discernible changes were evident only after several decades.

Fire

The most extensive studies on fire within the oakbrush zone were made by Baker (1949), who looked at soil changes, and McKell (1950), who studied the effects of fire on the vegetation itself.

Baker (1949) reported that after fire, pH of the soil increased by 0.1 to 0.7 units, and nitrogen, phosphorus, potassium, and soluble salts also increased; but soil moisture content was lower on burned areas, and there was less litter. The difference in soil organic content between burned and unburned areas was not statistically significant. Fire stimulated shoot growth.

McKell (1950) noted that fire stimulated shoot production of most shrub species that occur frequently with Gambel oak. He also found that most other plants increased in number following fire. But 9 years later he found no significant difference in the number of oak stems per unit area on burned and adjacent unburned areas. After 18 years, the area had returned to nearly its original vegetation. He suggested that the loss of plant cover through burning had more serious implications for soil stability than it did for plant cover, since most of the plants sprouted. Allman (1952) and Brown (1958) reported that fires are frequent in the oakbrush zone, but that fires kill only the stems of oak. Several shoots replaced each one destroyed by fire.

Although prolific sprouting occurs after burning, several authors have concluded that it can be minimized by seeding competitive grasses after fire (Frischknecht and Plummer 1955; Plummer and others 1966; Plummer and others 1970). Nevertheless, our examination of these authors' study plots forces us to conclude that additional studies are needed before their results can be accepted as conclusive. Clearing oakbrush with fire is feasible, but if improved forage conditions are the objective, burned areas must acquire heavier covers of grasses and forbs than existed initially. A mixture of grass species is usually recommended for seeding on burned sites (USDA Forest Service 1966; Plummer and others 1970), but the matter of suitable forbs for inclusion in seeding mixtures has received little study. Selection of suitable forbs for the oak zone merits further attention.

Smooth brome (*Bromus inermis*), intermediate wheatgrass (*Agropyron intermedium*), and crested wheatgrass (*A. cristatum*) are frequently recommended for seeding into burned or chained oak stands (Anon. 1966; Plummer and others 1966; 1970). Intermediate wheatgrass, pubescent wheatgrass (*A. intermedium* var. *trichophorum*), quackgrass (*A. repens*), meadow brome (*B. erectus*), and smooth brome have all been tried with success in central Utah (Frischknecht and Plummer 1955). Plummer and others (1968) have also had success with mountain brome (*B. carinatus*), orchardgrass (*Dactylis glomerata*), and tall oatgrass (*Arrhenatherum elatius*). They also list other species of grasses, forbs, and shrubs that may be added to seeding mixtures for general and special purposes.

Steinhoff (1978) reported how various wildlife species could be expected to respond to various management treatments in the Gambel oak zone. He included burning as one treatment for consideration (table 6). He also found that only the hermit thrush was intolerant to a cool burn in oak. About one-third of the species that were rated were listed as intolerant to a hot burn.

Dills (1970) reported that controlled burning provided more browse for deer by stimulating sprouting and permitting the penetration of more light to stimulate greater herbaceous growth. Evidence suggests that burning could be an effective and inexpensive tool for manipulation of oakbrush on deer ranges where a market does not exist for fuel wood or where slopes are too steep to permit fuel wood harvest.

Current law requires that land managers limit the emission of air pollutants from prescribed burns (Sandberg and others 1979). Before prescribed fires are started, managers must have enough information to demonstrate that standards will not be exceeded. This may necessitate some basic research to satisfy local regulations. Establishment of fire lanes and maintenance of a fire crew to ensure that controlled burns do not spread beyond the desired limits will increase costs, but are necessary.

Pearl (1965) is representative of some managers who believe that burning should be rejected as a control method for Gambel oak because of adverse effects on scenic, wildlife, soil, and economic values. Before fire is used as a management tool in the oak type, an attempt should be made to anticipate public response to its use at specific locations.

Herbicides

Since the mid-1960's, a number of reports on response of Gambel oak to various herbicides have appeared. Early research centered on 2,4,5-T, 2,4,5-TP (Silvex), picloram (marketed alone or in mixtures with various phenoxy herbicides as Tordon), and mixtures of any two of those chemicals. Initial experience demonstrated that Gambel oak was more resistant to herbicides than most plant species. Although all of the chemicals killed Gambel oak foliage, their effects were less lethal to stems and below-ground parts. Prolific sprouting occurred under at least some conditions after as many as three consecutive years of treatment of aboveground

parts with the herbicides (Heikes 1964; Jefferies 1965b; Pearl 1965; Marquiss and Norris 1967; Marquiss 1968, 1972, 1973). Field work showed that penetration was better and undesired drift was less when herbicides were applied in water-petroleum oil emulsions (Pearl 1965; Klingman and others 1982).

In the late 1960's and early 1970's, work continued with 2,4,5-T, 2,4,5-TP, and picloram alone and in mixtures with phenoxy herbicides, while newer herbicides were also tested. Johnson and others (1969) and Reynolds (1970) stated that of numerous herbicide trials reported for control of Gambel oak in Arizona, only a few were even moderately successful in reducing crown cover for long periods; vigorous sprouting followed application of almost all herbicides considered. Crowns could be reliably killed by treating trunk frills and girdles with saturated solutions of AMS (ammonium sulfamate, commonly marketed as Ammate), but sprouts quickly appeared. Vallentine and Schwendiman (1973) found that AMS used as a basal spray without trunk frills was relatively ineffective against Gambel oak. Basal applications of the ester form of 2,4,5-T in diesel oil and soil applications of pelletized fenuron (a urea-type herbicide) in the dormant season reduced sprouting (Johnson and others 1969). Vallentine and Schwendiman (1973) confirmed those results for basal sprays with 2,4,5-T. Marquiss (1973) applied 2.5 lb active ingredients (a.i.) per acre (1.1 kg a.i./0.4 ha) of fenuron pellets to the soil, but found that dosage ineffective against mature oak.

Marquiss (1969) studied the effects of nonstructural carbohydrate reserves in oak rhizomes and roots on susceptibility to herbicides. He found that mature trees apparently did not begin to replenish root reserves until about the time that full leaf size was achieved (late June or early July) in southwestern Colorado. He concluded that sprouting was about equally vigorous whether herbicides were applied in the spring or in the summer (Marquiss 1973). Working with rhizomes of young sprouts, Engle and Bonham (1980) came to a different conclusion; nonstructural carbohydrate content of rhizomes was lowest midway through the leaf expansion process. They believed that root kill would be enhanced if herbicides were applied when root reserves were most depleted. The assumption was that herbicides were more likely to be translocated to rhizomes and roots when nonstructural carbohydrates were being moved from leaves to underground parts at rapid rates. Engle and Bonham (1980) found that applications of herbicides after root reserves were replenished gave excellent stem kill, but stem crowns sprouted immediately and produced such vigorous sprouts that root and rhizome food reserves equaled and often exceeded those of control plants by season's end. Their results suggest that herbicide foliar applications on Gambel oak should be made well before leaf expansion is complete.

Marquiss (1971, 1972, 1973) demonstrated that phenoxy herbicides alone rarely gave over 50 percent stem kill after single applications at rates of up to 3.0 lb a.i./acre (1.36 kg a.i./0.4 ha); sprouting was usually abundant even after multiple treatments. Silvex at 3.0 lb a.i./acre (1.36 kg a.i./0.4 ha) was more effective, giving as much as 80 percent control (Marquiss 1972), but picloram mixed with either phenoxy herbicides or Silvex gave the best results for both stem kill and suppression of sprouting (Marquiss 1973). Bartel and others (1973) concluded that because Silvex-picloram mixtures controlled Gambel oak well and were essentially nontoxic to established grasses (but not to dicotyledonous shrubs and forbs), enhanced forage production in oak understories might sometimes offset the costs of herbicides and make such treatments economically feasible range improvement practices. Vallentine and Schwendiman (1973) agreed that Silvex-picloram mixtures (1:2 lb a.i./acre [0.45:0.91 kg a.i./0.4 ha]) applied to foliage caused heavy stem mortality and gave considerable control over sprouting, but they did not consider the treatment to be economically justified except for spot treatments where special needs warranted larger expenditures. Vallentine and Schwendiman also found picloram alone (4 lb a.i./acre [1.8 kg a.i./0.4 ha] applied to soil in granular form or as a basal spray at a rate of 8 lb a.i./100 gal [3.6 kg a.i./378 liters]), or basal spray of Silvex in diesel (16 lb a.i./100 gal [7.3 kg a.i./378 liters]), or 2,4,5-T (16 lb a.i./100 gal [7.3 kg a.i./378 liters]) gave nearly complete stem kill of oak and minimal sprouting. They also concluded that Bromacil (a uracil-type compound) at 12 lb a.i./100 gal (5.4 kg a.i./378 liters) as a basal spray gave nearly complete kill, but some stems took 3 years to die. They observed that Silvex, picloram, and Bromacil were translocated through rhizomes in sufficient quantity to kill plants over 10 ft (3 m) away.

Marquiss (1973) noted that the same herbicide treatment applied repeatedly gave "highly variable results from year to year." Thus, managers must realize that treatment prescriptions must be adjusted to local conditions for best results.

Van Epps (1974) ran extensive herbicide trials on Gambel oak in Utah. He found that fenuron applied as granules at 8 lb a.i./acre (3.6 kg a.i./0.4 ha) in the spring gave nearly complete control of mature oak stems without subsequent sprouting. The herbicide continued to cause injury 3 and 4 years after application despite the fact that it is reported to remain active in soil for only 3 to 12 months (Klingman and others 1982). Apparently, marginal amounts of precipitation at treatment sites failed to completely dissolve granules in the first 2 years after treatment. Fenuron was readily translocated through oak stems and caused injury to plants as much as 80 ft (24.4 m) from the point of application. The herbicide destroyed all understory growth (both monocots and dicots) in Van Epps' plots. Although fenuron gave better control over oak than any other herbicide tested (2,4,5-TP, picloram, and picloram mixed with 2,4-D or 2,4,5-T in various proportions), Van Epps did not recommend it because of its persistent soil sterilization effect.

Van Epps (1974) found that Tordon 225 (a mixture of equal parts of picloram and 2,4,5-T) applied as foliar spray at the rate of 6 lb/acre (2.72 kg/0.4 ha) consistently gave good control of mature oak stems (average of 87 percent reduction of canopy) and subsequent sprouting (average of 57 percent injury on sprouts) without harming grasses in the understory. Tordon 212 (a mixture of one part picloram and two parts 2,4-D) applied as foliar spray and Tordon 225 at 1 lb/acre

(1.8 kg/0.4 ha) concentration were nearly as effective as Tordon 225 at the heavier application noted above.

Most recent herbicide trials for control of oak have not included Gambel oak, but have involved several species that are morphologically or ecologically similar to that species. Work has continued with picloram, but primary emphasis has centered on tebuthiuron (a urea-type herbicide sometimes marketed as Spike or Graslan), karbutilate (classified as either a carbamate or urea-type herbicide, but with herbicidal properties more like the latter according to Klingman and others [1982]), and buthidazole (an organic herbicide). Working with *Quercus turbinella* in Arizona, Davis and others (1980) tentatively concluded after two growing seasons that "tebuthiuron was the most effective herbicide against shrub live oak, followed in decreased order by buthidazole, karbutilate, and picloram." All were applied to soil in granular form. At 2 lb a.i./acre (0.9 kg a.i./0.4 ha) applied in summer, tebuthiuron was more than twice as effective (84 percent kill of 1-year-old fire sprouts) as buthidazole at 2 lb a.i./acre (0.9 kg a.i./0.4 ha), equally as effective as 8 lb a.i./acre (3.6 kg a.i./0.4 ha) of karbutilate or 8 lb a.i./acre (3.6 kg a.i./0.4 ha) of picloram. Summer applications of tebuthiuron to mature oakbrush at a rate of 2 lb a.i./acre (0.9 kg a.i./0.4 ha) were three times as effective (62 percent stem kill) as karbutilate at the same rates of application. Buthidazole and picloram killed no mature stems at 8 lb a.i./acre (3.6 kg a.i./0.4 ha) whether applied in summer or winter. Davis and others (1980) suggested that a prescribed burn of overmature oak stands followed by soil-applied herbicide treatment of 1-year-old fire sprouts would reduce the amount of herbicide needed for equivalent levels of control. No clear pattern was discernible relative to the effectiveness of summer versus winter applications of the four herbicides tested. Tebuthiuron was most effective in summer applications in Arizona, but karbutilate usually performed best in winter trials.

Davis and Gottfried (1981) noted that Gambel oak was known to be sensitive to soil-applied tebuthiuron, but they presented no data. They observed poor response of mature Gambel oak (2 percent kill) to soil applications of picloram at a rate of 6.0 lb a.i./acre (2.7 kg a.i./0.4 ha) in Arizona.

Scifres and others (1981) demonstrated that in Texas, tebuthiuron applied to soil in the spring at a rate of 2.47 lb a.i./acre (1.12 kg a.i./0.4 ha) gave 99 percent control of blackjack oak (*Q. marilandica*), post oak (*Q. stellata*), and water oak (*Q. nigra*) 3 years after treatment. The first two species are similar to Gambel oak in growth form and ecology. More recently in Texas, Jacoby and others (1983) reported that tebuthiuron gave good control over Havard oak (*Q. havardii*), a species known to hybridize with Gambel oak and to occupy similar habitats in areas of geographic overlap. Tebuthiuron applied at 1.12 or 1.23 lb a.i./acre (5.1 or 5.6 kg a.i./0.4 ha) killed all mature trees at two sites and gave almost complete control of sprouts for at least 30 months. Tebuthiuron apparently has no deleterious effects on grasses (annual or perennial) at rates normally effective against oak, but its effect on forbs and a wide variety of shrubs other than oak is lethal or at least suppressive (Jacoby and others 1983). Tebuthiuron may remain active in soil for over 12 months even after pellets have dissolved and washed into the soil (Klingman and others 1982), but the effects on forbs appeared to be gone after about 15 months in the study by Jacoby and others (1983).

The relatively long active life of tebuthiuron in the environment has the potential for serious problems should runoff from treated areas be used for irrigation. Davis (1981) investigated the degree to which tebuthiuron accumulated in runoff from a treated watershed in Arizona. Tebuthiuron had been applied at a rate of 4.0 lb a.i./acre (1.8 kg a.i./0.4 ha) in pellets having 20 percent by weight active ingredients. Stream water from the treated watershed was analyzed for the herbicide for 16 months after treatment. Rainfall was unusually heavy during the period of analysis (over 61 inches [155 cm]), yet less than 0.7 percent of the applied herbicide found its way into the stream. Herbicide concentrations in the water never exceeded 0.01 ppm, and none could be detected in the stream after the 18th day following treatment. This herbicide is not considered to be toxic to farm animals or fish (Klingman and others 1982).

The success of tebuthiuron against other oak species suggests that it should be considered for future herbicide trials with Gambel oak. As with all soil-applied herbicides, treatments will be most effective on coarse-textured and highly permeable soils and in regions where precipitation is sufficient to quickly dissolve pellets and carry the chemical into the soil (USDA Forest Service 1983).

Engle and others (1983) argued that because Gambel oak had not been controlled completely at economically acceptable rates of application by any herbicide, managers should shift their emphasis from destruction of the plant to investigation of its inherent values and of the landscapes where it is a natural dominant. Their point seems worthy of consideration. Studies demonstrate that the first 25 percent of shrub canopy coverage is the most detrimental to understory production (Kennedy 1971; Jacoby and others 1983). Thus, significant sprouting after treatment quickly erodes forage increases arising from that treatment. Furthermore, gains in runoff water achieved by destruction of mature oak stems are lost within 3 years, if those stems sprout (Tew 1967; Marquiss 1972). In any event, managers should carefully weigh the economics of converting oak woodland to herbland for improvement of either forage or water production. Such analyses will require current estimates of costs of herbicides and their application and of values for grazing animal carrying capacity and water production of the site before and after treatment. The expected longevity of the improved carrying capacity or water yield is also needed for economic evaluation of alternatives. Gaylord (1982) has provided a convenient format for predicting net profit or loss per unit area per year when such facts are known.

Steinhoff (1978) categorized the response of wildlife species to chemical control of oak in Colorado. Only three of his seven Gambel oak associations had more than two species of wildlife rated. In his oak—serviceberry—Oregon-grape assocation, oak-serviceberry

association, and the pure oak type, 22 wildlife species were rated. Of those, only four were rated as intolerant to chemical control of oak. Intolerant species were the ferruginous hawk, great horned owl, green-tailed towhee, and the lesser goldfinch (*Carduelis psaltria*).

As with fire, Pearl (1965) felt that conventional herbicide treatments should be rejected because of adverse impacts on scenic, wildlife, soil, and other resource values. There is also resistance to the use of some herbicides (notably 2,4,5-T) because of alleged adverse effects on human health (Smith 1979).

Mechanical Manipulation

Mechanical treatments of Gambel oak involve the use of machinery to physically break down the brush. The more common treatments include anchor chaining, brush raking, bulldozing, roller chopping, and root plowing. Of these, twice-over anchor chaining is considered by many workers as the best treatment for preparing oak stands for reseeding to herbs (Anon. 1966; Marquiss 1971; Plummer and others 1966, 1968; Davis and others 1973, 1975).

Because of prolific sprouting after mechanical treatments, a good followup program is needed to control oak regrowth (Marquiss 1971). Many authors have stated that quick establishment of competitive herbs is an effective way to do this (Anon. 1966; Plummer and others 1966, 1968, 1970). An anonymous (1966) report stated that seeding with smooth brome, intermediate wheatgrass, and crested wheatgrass had been effective in retarding oak regrowth and had increased deer use from 15 to 65 deer days per acre (37 to 160.6 days/ha). Price (1938) showed favorable results when mountain brome, smooth brome, and crested wheatgrass were used. He also reported heavy deer use on treated areas. Plummer and others (1966, 1970) recommend reseeding with smooth brome, intermediate wheatgrass, and fairway crested wheatgrass. They stated that grazing by both deer and cattle supplemented competition from grasses in keeping browse within reach of grazing animals. Forsling and Dayton (1931) listed many species that can be seeded into oak stands as well as the general environmental requirements of each. They also suggested mechanical methods for the reseeding task. Plummer and others (1968) listed several seed mixtures that do well in different mountain brush types.

Bleich and Holl (1982) provided a general discussion of the response of mule deer to the proportion and pattern of brush and open patches in the chaparral types of California. Many of their conclusions seem applicable to design of mechanical treatments in Gambel oak stands. They concluded that the ratio of brush to open foraging areas is optimal for mule deer at about 1:9. Brush patches should be about 25 acres (10 ha) in size to be optimally useful as escape cover and should be well distributed throughout the foraging areas. Bleich and Holl also gave comparative costs for controlling brush in California by means of mechanical, chemical, hand removal, burning, and grazing methods.

Because goats consume buds and leaves of Gambel oak, heavy stocking with goats after removal of top growth of oak is recommended as an effective followup treatment to control sprouting (Davis and others 1973, 1975). Chapline (1919) and Nastis and Malechek (1981) considered oakbrush to be acceptable forage for goats. Goats are potentially capable of efficiently converting oakbrush to red meat and may be able to extend the economically profitable life of oak stands treated to enhance herbaceous forage production. Goats in combination with cattle could significantly increase the carrying capacity of many oak-dominated rangelands (Davis and others 1975; Nastis and Malechek 1981). Studies suggest that goats will consume considerable browse even when an abundance of palatable grass is available (Martin and Huss 1981). Knipe (1982) warned, however, that Angora goats relished young grass; they could be detrimental in management schemes if the objective was to suppress oak in order to enhance success of interseeded forage grasses.

Recent changes in the energy situation in the United States require a reevaluation of the values of Gambel oak as fuel wood. The species grows in extensive stands close to many population centers. On gentler slopes, oak could supply considerable fuel wood without adverse impacts on the environment. In such situations, stands could be opened up for grazing by domestic livestock or big game by harvesting fuel wood. As noted earlier, the species' wood has a very high energy content per unit volume. Fuel wood harvests could achieve roughly the same range forage production objectives as burning, herbicide treatments, or other mechanical manipulations. Revenue from sale of oak fuel wood could partially or completely defray cost of treatments to enhance forage production in oak stands.

Toland (1982) discussed the potential for using brush types structurally similar to the Gambel oak type for energy. He envisioned a time when sprouting brush types would be harvested with choppers that would remove top growth without destroying roots. Chips could be compressed into small cubes or logs that could be sold directly, gasified, pyrolyzed, or used to generate electricity. He called for development of harvesters that could work terrain of up to 30 percent slope without serious soil disturbance. He noted that most native woods produced emissions on burning that were so low in oxides of sulfur and nitrogen that emission control devices would not be needed for their use. Furnaces burning high-sulfur-content coal are required to have devices that control sulfur in gases emitted from the furnace.

Escalating fuel costs may eventually make it possible to manage more productive clones of Gambel oak on certain sites for fuel wood as the primary product. However, fuel wood production would probably not be an acceptable management option on a large percentage of the land dominated by this oak. Other mechanical treatments, fire, or herbicides will probably remain more desirable alternatives on steep (over 30 percent) slopes, sites where wood production can be expected to be low for environmental or genetic reasons, and sites far removed from potential markets.

Mechanical treatments are referred to as "cutting" by Steinhoff (1978). He rated associated animals in seven Gambel oak associations of Colorado as intolerant or tolerant of cutting. He found that roughly a quarter of the animal species could be expected to be intolerant of cutting, and three-fourths to be tolerant (table 6).

Pearl (1965) rejected mechanical treatments because of adverse impacts on scenic, wildlife, soil, or economic values in the various Gambel oak types.

CONCLUSIONS

Gambel oak is a major component of the vegetation on more than 9.3 million acres (3.76 million ha) in the Western United States. The species generally grows as a large shrub, but assumes the stature of a small tree on better sites throughout its range. The species provides shelter, forage, and mast for a variety of wild animals. Domestic grazers also harvest large amounts of forage from the species. Its wood is hard and has a very high energy content per unit volume. It is readily accepted as a fuel wood by homeowners and commercial wood harvesters.

Many decades of domestic grazing have resulted in reduction of palatable herbaceous growth in the understory of Gambel oak stands and an increase in the cover of both oak and associated shrubs. Fire control has permitted less fire-tolerant climax species, such as canyon maple, Rocky Mountain juniper, or white fir, to increase at the expense of oak, a fire-tolerant species. Secondary plant succession is producing significant changes in the oak zone that are not well understood.

Older oak stands often have little forage within reach of big game and domestic grazing animals. In addition, some younger stands are so dense as to be nearly impenetrable by large animals. Fire, herbicides, and mechanical treatments have been used to reduce the dominance of oak and unpalatable shrubs, place more usable forage within reach of grazing animals, and permit easier access to grazers. Oak sprouts prolifically after most treatments. Thus, treated stands should be seeded with desirable and competitive herbs capable of persisting in the community. Such competitors may keep oak from exerting total dominance over the site. Palatable herbs also improve the quality of available forage at treated sites.

Each kind of control treatment has advantages and problems. Most mechanical treatments cannot be used on steep slopes. Herbicide and fire treatments may lead to water or air pollution and often both are objected to by some people. Escalating energy costs have again led to heavy demands for fuel wood for private homes. Because large acreages of oak occur near major metropolitan centers in the West, fuel wood sales provide a valuable management tool for opening up old oak stands that occur on relatively gentle terrain. Fuel wood harvesting could achieve desirable management goals on some sites and simultaneously return revenue to the land management agency. On steep sites and sites far from human population centers, fire, herbicides, and mechanical treatments may continue to be useful management tools.

REFERENCES

Allan, J. S. The plant communities of the Big Cottonwood Canyon drainages. Salt Lake City, UT: University of Utah; 1962. 108 p. M.S. thesis.

Allman, V. P. A preliminary study of the vegetation in an exclosure in the chaparral of the Wasatch Mountains, Utah. Provo, UT: Brigham Young University; 1952. 236 p. M.S. thesis.

Allman, V. P. A preliminary study of the vegetation in an exclosure in the chaparral of the Wasatch Mountains, Utah. Proceedings of Utah Academy of Science, Arts, and Letters. 30: 63-73; 1953.

Anonymous. World's largest scrub oak found in southern Utah. Utah Fish and Game Bulletin. 5(10): 4-5; 1948.

Anonymous. Conversion of the thicket covered areas to productive grazing land. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Region; 1966; Range Improvement Notes. 11(4): 1-4.

Antevs, E. Geologic-climatic dating in the West. American Antiquity. 20: 317-335; 1955.

Arnold, J. F.; Olson, O. C. Soil management report: Kamas Ranger District, Wasatch National Forest. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Region; 1962. 214 p. Mimeograph.

Astatke, H. Oak defoliation and understory plants. Fort Collins, CO: Colorado State University; 1967. 62 p. M.S. thesis.

Baker, F. S.; Korstian, C. F. Suitability of brushlands in the Intermountain Region for the growth of natural or planted western yellow pine forests. Technical Bulletin 256. Washington, DC: U.S. Department of Agriculture; 1931. 82 p.

Baker, W. L. Soil changes associated with recovery of scrub oak, *Quercus gambelii*, after fire. Salt Lake City, UT: University of Utah; 1949. 65 p. M.S. thesis.

Barger, R. L.; Ffolliott, P. F. Physical characteristics and utilization of major woodland tree species in Arizona. Research Paper RM-3. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station; 1972. 80 p.

Bartel, L. E.; Davis, G. D.; Cook, C. W. Production benefits from Gambel oak control in southwestern Colorado. Progress Report PR73-11. Fort Collins, CO: Colorado Agriculture Experiment Station; 1973. 3 p.

Bartel, L. E.; Rittenhouse, L. R. Herbicidal control of Gambel oak root sprouts in southwestern Colorado. Down to Earth. 36(1): 6-9; 1979.

Behle, W. H.; Perry, M. L. Utah birds—guide, check-list, and occurrence charts. Salt Lake City, UT: University of Utah, Utah Museum of Natural History; 1975. 144 p.

Black, H. L. Differential utilization of bat boxes by house wrens (*Troglodytes aedon*). Great Basin Naturalist. 43: 456; 1983.

Bleich, V. C.; Holl, S. A. Management of chaparral habitat for mule deer and mountain sheep in southern California. In: Conrad, C. E.; Oechel, W. C., technical

coordinators. Dynamics and management of Mediterranean-type ecosystems. General Technical Report PSW-58. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station; 1982: 247-254.
Bradley, W. G.; Deacon, J. E. The biotic communities of southern Nevada. Prepublication Series 9. Reno, NV: University of Nevada, Desert Research Institute; 1965. 86 p.
Branson, F. A.; Gifford, G. F.; Renard, K. G.; Hadley, R. F. Rangeland hydrology. 2d ed. Dubuque, IA: Kendall/Hunt Publishing Company; 1981. 340 p.
Brewster, W. W. The gall wasps (Hymenoptera: Cynipidae) producing galls on scrub oak, *Quercus gambelii* Nuttall in Salt Lake County. Salt Lake City, UT: University of Utah; 1951. 43 p. M.S. thesis.
Brotherson, J. D.; Evenson, W. E.; Rushforth, S. R.; Fairchild, J.; Johansen, J. Spatial patterns of plant communities in Navajo National Monument, Arizona. In: Brotherson, J. D., ed. Ecological studies at Navajo Monument, part II. Report to National Park Service, Navajo National Monument, Kayenta, AZ; mimeographed; 1980. 47 p.
Brotherson, J. D.; Rushforth, S. R.; Evenson, W. E.; Johansen, J. R.; Morden, C. Population dynamics and age relationships of eight tree species in Navajo National Monument, Arizona. Journal of Range Management. 36: 250-256; 1983.
Brotherson, J. D.; Szyska, L. A.; Evenson, W. E. Bird community composition in relation to habitat and season in Betatakin Canyon, Navajo National Monument, Arizona. Great Basin Naturalist. 41: 298-309; 1981.
Brown, H. E. Gambel oak in west central Colorado. Ecology. 39: 317-327; 1958.
Brown, R. C.; Mogensen, H. L. Late ovule and early embryo development in *Quercus gambelii*. American Journal of Botany. 59: 311-316; 1972.
Chamberlain, R. V. The ethnobotany of the Goshute Indians. Philadelphia, PA: Proceedings of the Academy of Natural Science. 63: 24-99; 1911.
Chapline, W. R. Production of goats on far western ranges. Bulletin 749. Washington, DC: U.S. Department of Agriculture; 1919. 35 p.
Christensen, E. M. The ecology and geographic distribution of oak (*Quercus gambelii*) in Utah. Salt Lake City, UT: University of Utah; 1949. 70 p. M.S. thesis.
Christensen, E. M. Distibutional observations of oakbrush (*Quercus gambelii*) in Utah. Proceedings of Utah Academy of Science, Arts, and Letters. 27: 22-25; 1950.
Christensen, E. M. Ecological notes on the mountain brush in Utah. Proceedings of Utah Academy of Science, Arts, and Letters. 32: 107-111; 1955.
Christensen, E. M. Photographic history of the mountain brush on "Y" Mountain, central Utah. Proceedings of Utah Academy of Science, Arts, and Letters. 34: 154-155; 1957.
Christensen, E. M. Growth rates and vegetation changes in the oak-maple brush in lower Provo Canyon, Utah. Proceedings of Utah Academy of Science, Arts, and Letters. 35: 167-168; 1958.
Christensen, E. M. A comparative study of the climates of mountain brush, pinyon-juniper, and sagebrush communities in Utah. Proceedings of Utah Academy of Science, Arts, and Letters. 36: 174-175; 1959.
Christensen, E. M. Succession in a mountain brush community in central Utah. Proceedings of Utah Academy of Science, Arts, and Letters. 41: 10-13; 1964.
Clokey, I. W. Flora of the Charleston Mountains, Clark County, Nevada. Berkeley, CA: University of California Press; 1951. 274 p.
Costello, D. A.; Turner, G. T. Vegetation changes following exclusion of livestock from grazed ranges. Journal of Forestry. 39: 310-315; 1941.
Cottam, W. P.; Evans, F. R. A comparative study of grazed and ungrazed canyons of the Wasatch Ranges, Utah. Ecology. 26: 171-181; 1945.
Cottam, W. P.; Tucker, J. M.; Drobnick, R. Some clues to Great Basin post pluvial climates provided by oak distribution. Ecology. 40: 361-377; 1959.
Croft, A. R. Some recharge and discharge phenomena of north- and south-facing watershed-lands in the Wasatch Mountains. In: Transcripts of 1940 American Geophysics Union; 1944: 881-889.
Cronquist, A. A.; Holmgren, A. H.; Holmgren, N. H.; Reveal, J. L. Intermountain flora-vascular plants of the Intermountain West, U.S.A. Volume I. New York: Hafner Publishing Company; 1972. 270 p.
Crowther, E. G.; Harper, K. T. Vegetational and edaphic characteristics associated with aspen "strips" in Big Cottonwood Canyon. Proceedings of Utah Academy of Science, Arts, and Letters. 42(2): 222-230; 1965.
Davis, E. A. Propagation of a shrub live oak from cuttings. Botanical Gazette. 131: 55-61; 1970.
Davis, E. A. Tebuthiuron residues in stream-water from a spot-treated chaparral watershed in Arizona. In: 1981 research progress report. San Diego, CA: Western Society of Weed Science; 1981: 52-53.
Davis, E. A.; Gottfried, G. J. Response of New Mexico locust and Gambel oak to picloram pellets. In: 1980 research progress report. Salt Lake City, UT: Western Society of Weed Science; 1981: 54-55.
Davis, E. A.; Rieger, N.; Bryant, D. A. Tests of soil-applied chemicals for chaparral management in Arizona. In: 1980 research progress report. Salt Lake City, UT: Western Society of Weed Science; 1980: 77-79.
Davis, G. D.; Bartel, L. E.; Cook, C. W. Mechanical and biological methods of controlling Gambel oak in southwestern Colorado. Research Paper PR73-12. Fort Collins, CO: Colorado Agricultural Experiment Station; 1973. 3 p.
Davis, G. D.; Bartel, L. E.; Cook, C. W. Control of Gambel oak sprouts by goats. Journal of Range Management. 28: 216-218; 1975.
Davis, R. J. Flora of Idaho. Dubuque, IA: William C. Brown; 1952. 828 p.
Dayton, W. A. Important western browse plants. Miscellaneous Publication 101. Washington, DC: U.S. Department of Agriculture; 1931. 212 p.
Dick-Peddie, W. A.; Moir, W. H. Vegetation of the Organ Mountains, New Mexico. Series 4. Fort Collins, CO: Colorado State University Range Science Department; 1970. 28 p.

Dietz, D. R. Seasonal variation in the nutritive content of five southwestern Colorado deer browse species. Fort Collins, CO: Colorado State University; 1958. 110 p. M.S. thesis.

Dills, G. G. Effects of prescribed burning on deer browse. Journal of Wildlife Management. 34: 540-545; 1970.

Dina, S. J. An evaluation of physiological response to water stress as a factor influencing the distribution of six woody species in Red Butte Canyon, Utah. Salt Lake City, UT: University of Utah; 1970. 117 p. Ph.D. dissertation.

Dina, S. J.; Klikoff, L. G. Carbon dioxide exchange by several stream-side and scrub oak community species of Red Butte Canyon, Utah. American Midland Naturalist. 89: 234-239; 1973.

Dina, S. J.; Klikoff, L. G.; Keddington, M. B. Seasonal water potential patterns in the mountain brush zone, Utah. American Midland Naturalist. 89: 70-80; 1973.

Dixon, H. Ecological studies on the high plateaus of Utah. Botanical Gazette. 97: 272-320; 1935.

Dortignac, E. J. Watershed resources and problems of the Upper Rio Grande Basin. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station; 1956. 107 p. Unpublished.

Drobnick, R. The ecology of a relic hybrid oak in the Great Basin area of Utah. Salt Lake City, UT: University of Utah; 1958. 96 p. M.S. thesis.

Eastmond, R. J. Vegetative changes in a mountain brush community through eighteen years. Provo, UT: Brigham Young University; 1968. 64 p. M.S. thesis.

Eastmond, R. J.; Christensen, E. M. Vegetational changes in a mountain brush community during eighteen years. Proceedings of Utah Academy of Science, Arts, and Letters. 45: 317-318; 1968.

Ellison, L. Influence of grazing on plant succession of rangelands. Botanical Review. 26: 1-78; 1960.

Engle, D. M. Root carbohydrate reserves and herbicidal control of Gambel oak sprouts. Fort Collins, CO: Colorado State University; 1978. 71 p. Ph.D. dissertation.

Engle, D. M.; Bonham, C. D. Nonstructural carbohydrates in roots of Gambel oak sprouts following herbicide treatment. Journal of Range Management. 33: 390-394; 1980.

Engle, D. M.; Bonham, C. D.; Bartel, L. E. Ecological characteristics and control of Gambel oak. Journal of Range Management. 36: 363-365; 1983.

Erdman, K. S. Distribution of the native trees of Utah. Science Bulletin: Biological Series. Provo, UT: Brigham Young University; 1961; 11: 1-34.

Evans, F. R.; Grundmann, A. W. Further observations on bacteriological sterility of the chamber of Cynipid-induced galls on *Quercus gambelii* Nuttall. Journal of Kansas Entomological Society. 27: 148-151; 1954.

Flowers, S. Vegetation of Glen Canyon. Anthropology Paper 40. Salt Lake City, UT: University of Utah; 1959: 21-72.

Floyd, M. E. The interaction of pinyon pine and Gambel oak in plant succession near Dolores, Colorado. Southwestern Naturalist. 27: 143-147; 1982.

Forsling, C. L.; Dayton, W. A. Artificial reseeding on western mountain range lands. Circular 178. Washington, DC: U.S. Department of Agriculture; 1931. 48 p.

Forsling, C. L.; Storm, E. V. The utilization of browse forage as summer range for cattle in southwestern Utah. Circular 62. Washington, DC: U.S. Department of Agriculture; 1929. 29 p.

Freeman, D. C.; McArthur, E. D.; Harper, K. T.; Blauer, C. The influence of environment on the floral sex ratio of monoecious plants. Evolution. 35: 194-197; 1981.

Frischknecht, N. C.; Plummer, A. P. A comparison of seeded grasses under grazing and protection on a mountain brush burn. Journal of Range Management. 8: 170-175; 1955.

Frost, H. H. A seasonal study of the food of some birds of the Wasatch chaparral. Provo, UT: Brigham Young University; 1947. 68 p. M.S. thesis.

Furniss, M. M.; Barr, W. F. Insects affecting important native shrubs of northwestern United States. General Technical Report INT-19. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1975. 64 p.

Garrett, A. O. Spring flora of the Wasatch Region. 4th ed. Salt Lake City, UT: Stevens and Wallis; 1927. 193 p.

Gaylord, R. A. Evaluating the economics of brush control. Rangelands. 4: 151-153; 1982.

Graham, E. H. Botanical studies in the Uinta Basin of Utah and Colorado. Pittsburgh, PA: Annals Carnegie Museum. Vol. 26; 1937. 432 p.

Grover, B. L.; Campbell, C. B.; Campbell, M. D. A prediction equation for vegetation effects on water yield in arid areas. Soil Science Society of America Proceedings. 34: 669-673; 1970a.

Grover, B. L.; Richardson, E. A.; Southard, A. R. *Quercus gambelii* as an indicator of climatic means. Proceedings of Utah Academy of Science, Arts, and Letters. 47: 187-191; 1970b.

Grundmann, A. W. Notes on *Andricus pilula* Bassett (Hymenoptera, Cynipidae) producing a vernal gall on *Quercus gambelii* Nuttall in northern Utah. Journal of Kansas Entomological Society. 24: 28-30; 1951.

Grundmann, A. W.; Evans, F. R. A study of the bacterial flora of certain gall wasps (Hymenoptera, Cynipidae) affecting scrub oak (*Quercus gambelii* Nuttall). Journal of Kansas Entomological Society. 25: 66-68; 1952.

Hallisey, D. M.; Wood, G. W. Prescribed fire in shrub oak habitat in central Pennsylvania. Journal of Wildlife Management. 40: 507-516; 1976.

Harper, K. T.; Alder, G. M. The macroscopic plant remains of the deposits of Hogup Cave, Utah, and their paleoclimatic implications. In: Aikens, C. M. Hogup Cave. Salt Lake City, UT: University of Utah Anthropology Papers. 93: 215-240; 1970.

Harper, K. T.; Alder, G. M. Paleoclimatic inferences concerning the last 10,000 years from a resampling of Danger Cave, Utah. Desert Research Institute Publications in Social Science. Reno, NV: Desert Research Institute; 1972; 8: 13-23.

Harper, K. T.; Freeman, D. C.; Ostler, W. K.; Klikoff, L. G. The flora of Great Basin mountain ranges: diver-

sity, sources, and dispersal ecology. Great Basin Naturalist Memoirs. 2: 81-103; 1978.

Harrington, H. D. Manual of the plants of Colorado. Denver, CO: Sage Books; 1954. 666 p.

Hawksworth, F. G.; Mielke, J. L. Witches' broom of Gambel oak associated with *Articularia quercina* var. *minor*. Phytopathology. 52: 451-454; 1962.

Hayward, C. L. Biotic communities of the Wasatch chaparral, Utah. Ecological Monographs. 18: 473-506; 1948.

Hedgcock, G. G.; Long, W. H. Heart-rot of oaks and poplars caused by *Polyporus dryophilus*. Journal of Agricultural Research. 3: 65-77; 1914.

Heikes, E. E. Tordon and other herbicides: field testing for control of deep-rooted perennial weeds in Colorado. Down to Earth. 20: 9-12; 1964.

Hoffman, D. M. The wild turkey in eastern Colorado. Project W-96-D. Colorado Game and Fish Department; 1962. 47 p.

Horton, L. E. An abstract bibliography of Gambel oak (*Quercus gambelii* Nuttall). Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Region, Range Management Staff; 1975. 64 p.

Hutchings, S. S.; Mason, L. R. Estimating yields of Gambel oak from foliage cover and basal area. Journal of Range Management. 23: 430-434; 1970.

Jacoby, P. W.; Slosser, J. E.; Meadors, C. H. Vegetational responses following control of sand shinnery oak with tebuthiuron. Journal of Range Management. 36: 510-512; 1983.

Jefferies, N. W. Herbage production on a Gambel oak range in southwest Colorado. Journal of Range Management. 18: 212-213; 1965a.

Jefferies, N. W. Herbicide studies on Gambel's oak in southwestern Colorado. In: 1965 progress report. Albuquerque, NM: Western Weed Control Conference; 1965b: 39-40.

Johnsen, T. N.; Clary, W. P.; Ffolliott, P. F. Gambel oak control on the Beaver Creek Pilot Watershed in Arizona. Crops Research Bulletin ARS34-104. Washington, DC: U.S. Department of Agriculture, Agricultural Research Service; 1969. 8 p.

Johnson, C. M. Common native trees of Utah. Special Report 22. Logan, UT: Utah Agricultural Experiment Station; 1970. 109 p.

Johnston, R. S.; Tew, R. K.; Doty, R. D. Soil moisture depletion and estimated evaporation on Utah mountain watersheds. Research Paper INT-67. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1969. 13 p.

Julander, O. Deer and cattle relations in Utah. Forest Science. 1: 130-139; 1955.

Julander, O.; Robinette, W. L. Deer and cattle range relationships on Oak Creek Range in Utah. Journal of Forestry. 48: 410-415; 1950.

Kay, L. One of the oldest trees on earth found in Utah (*Quercus gambelii*). Salt Lake (UT) Times. 1948 June 18: 1, 8.

Kearney, T. H.; Peebles, R. H. Arizona flora. Berkeley, CA: University of California Press; 1960. 1085 p.

Keddington, M. B. Moisture stress in five woody species of Big Cottonwood Canyon. Salt Lake City, UT: University of Utah; 1970. 35 p. M.S. thesis.

Keith, J. O. The Abert squirrel and its dependence on ponderosa pine. Ecology. 46: 150-163; 1965.

Kelly, G. W. A guide to the woody plants of Colorado. Boulder, CO: Pruett Publications; 1970. 180 p.

Kennedy, R. P. Decision-making help for brush control. Rangeman's News. Denver, CO: Society for Range Management; 1971 October: 8.

Kleiner, E. F. A study of the vegetational communities of Red Butte Canyon, Salt Lake County, Utah. Salt Lake City, UT: University of Utah; 1966. 54 p. M.S. thesis.

Klingman, G. C.; Ashton, F. M.; Noordhoff, L. J. Weed science: principles and practices. 2d ed. New York: John Wiley and Sons; 1982. 449 p.

Knipe, O. D. Angora goats for conversion of Arizona chaparral: early results. In: Conrad, C. E.; Oechel, W. C. technical coordinators. Dynamics and management of Mediterranean-type ecosystems. General Technical Report PSW-58. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station; 1982: 264-269.

Knipe, T. The javelina in Arizona. Wildlife Bulletin 2. Phoenix, AZ: Arizona Fish and Game Department; 1957. 96 p.

Knowlton, G. F. Studies on western aphids. Proceedings of Utah Academy of Science, Arts, and Letters. 18: 65-68; 1941.

Kolstad, C. D. The 1975 energy production system in the States of the Rocky Mountain region. Publication LA-6624. Los Alamos, NM: University of California, Los Alamos Science Laboratory; 1976. 115 p.

Kuchler, A. W. Potential natural vegetation of the conterminous United States. Special Publication 36 (map). New York, NY: American Geography Society; 1964.

Kufeld, R. C. Experimental improvements of oakbrush on deer, elk, and cattle ranges - Beaver Creek. In: Game research report July 1970. Fort Collins, CO: Colorado Department of Game, Fish, and Parks; 1970a: 97-106.

Kufeld, R. C. Experimental improvements of oakbrush on deer, elk, and cattle ranges - Hightower Mountain. In: Game research report July 1970. Fort Collins, CO: Colorado Department of Game, Fish, and Parks; 1970b: 115-121.

Kufeld, R. C. Foods eaten by the Rocky Mountain elk. Journal of Range Management. 27: 106-113; 1973.

Kufeld, R. C.; Stevens, M.; Bowden, D. C. Winter variation in nutrient and fiber content and in vitro digestibility of Gambel oak (*Quercus gambelii*) and big sagebrush (*Artemisia tridentata*) from diversified sites in Colorado. Journal of Range Management. 34: 149-151; 1981.

Kufeld, R. C.; Wallmo, D. D.; Feddema, C. Food of the Rocky Mountain mule deer. Research Paper RM-111. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station; 1973. 31 p.

Kunzler, L. M.; Harper, K. T. Recovery of Gambel oak after fire in central Utah. Great Basin Naturalist. 40: 127-130; 1980.

Kunzler, L. M.; Harper, K. T.; Kunzler, D. Compositional similarity within the oakbrush type in central and northern Utah. Great Basin Naturalist. 41: 147-153; 1981.

LaMarche, V. C.; Mooney, H. A. Recent climatic change and development of the bristlecone pine (*Pinus longaeva* Bailey) Krummholz zone, Mount Washington, Nevada. Arctic and Alpine Research. 4: 61-72; 1972.

Lamb, S. H. Woody plants of New Mexico and their value to wildlife. Bulletin 14. Albuquerque, NM: New Mexico Department of Game and Fish; 1971: 1-80.

Laycock, W. A. Exclosure and natural areas on rangelands in Utah. Research Paper INT-62. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1969. 44 p.

Ligon, J. S. History and management of Merriam's wild turkey. Sante Fe, NM: New Mexico Game and Fish Commission Report; 1946. 84 p.

Little, E. L., Jr. Atlas of United States trees, vol. 1. Conifers and important hardwoods. Miscellaneous Publication 1146. Washington, DC: U.S. Department of Agriculture, Forest Service; 1971. 19 p. plus 200 maps.

Little, E. L., Jr. Atlas of United States trees, vol. 3. Minor western hardwoods. Miscellaneous Publication 1314. Washington, DC: U.S. Department of Agriculture, Forest Service; 1976. 27 p. plus 210 maps.

Lull, H. W.; Ellison, L. Precipitation in relation to altitude in central Utah. Ecology. 31: 479-484; 1950.

Markham, B. S. A preliminary study of the vegetative cover in Spanish Fork Canyon, Utah. Provo, UT: Brigham Young University; 1939. 79 p. M.S. thesis.

Marquiss, R. W. Progress in chemical control of Gambel's oakbrush rangelands. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Region; Range Improvement Notes. 1968; 13: 7-8.

Marquiss, R. W. Studies on Gambel oak at the San Juan Basin Station. Progress Report 69-38. Fort Collins, CO: Colorado Agricultural Experiment Station; 1969. 2 p.

Marquiss, R. W. Controlling Gambel oak on rangelands of southwestern Colorado. Progress Report PR71-9. Fort Collins, CO: Colorado Agricultural Experiment Station; 1971. 2 p.

Marquiss, R. W. Soil moisture, forage, and beef production benefits from Gambel oak control in southwestern Colorado. Journal of Range Management. 25: 146-150; 1972.

Marquiss, R. W. Gambel oak control studies in southwestern Colorado. Journal of Range Management. 26: 57-58; 1973.

Marquiss, R. W.; Davis, G.; Bartel, L. Benefits derived from controlling Gambel oak in southwestern Colorado. Progress Report 71-10. Fort Collins, CO: Colorado Agricultural Experiment Station; 1971. 3 p.

Marquiss, R. W.; Norris, J. J. Management and improvements of Gambel oakbrush ranges. Progress Report 231. Fort Collins, CO: Colorado Agricultural Experiment Station; 1967. 2 p.

Marsh, C. D.; Clawson, A. B.; Marsh, H. Oak leaf poisoning of domestic animals. Bulletin 767. Washington, DC: U.S. Department of Agriculture; 1919. 38 p.

Marti, C. D. Avian use of an oakbrush community in northern Utah. Southwestern Naturalist. 22: 367-374; 1977.

Martin, J. A.; Huss, D. L. Goats much maligned but necessary. Rangelands. 3: 199-201; 1981.

Mason, L.; West, N. E. Timber Top Mesa: a relict area in Zion National Park. Proceedings of Utah Academy of Science, Arts, and Letters. 47: 284-285; 1970.

Mason, L. R.; Andrews, H. M.; Carley, J. A.; Haacke, E. D. Vegetation and soils of No Man's Mesa relict area. Journal of Range Management. 20: 45-49; 1967.

Maze, J. R. Past hybridization between *Quercus macrocarpa* and *Quercus gambelii*. Brittonia. 20: 321-333; 1968.

McCulloch, C. Y.; Wallmo, D. C.; Ffolliott, P. F. Acorn yield of Gambel oak in northern Arizona. Research Note RM-48. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station; 1965. 2 p.

McKell, C. M. A study of plant succession in the oak brush (*Quercus gambelii*) zone after fire. Salt Lake City, UT: University of Utah; 1950. 79 p. M.S. thesis.

Merriam, C. H. Results of a biological survey of the San Francisco Mountain Region and the desert of the Little Colorado, Arizona. North American Fauna. 3: 1-136; 1890.

Moinat, A. D. Comparative yields of herbage from oak scrub and interspersed grasslands in Colorado. Ecology. 37: 852-854; 1956.

Mogensen, H. L. Fine structure and composition of the egg apparatus before and after fertilization in *Quercus gambelii*: the functional ovule. American Journal of Botany. 59: 931-941; 1972.

Muenscher, W. C. Poisonous plants of the United States. New York: MacMillan Company; 1957. 266 p.

Muller, C. H. The significance of vegetative reproduction in *Quercus*. Madrono. 11: 129-137; 1951.

Nastis, A. S.; Malechek, J. C. Digestion and utilization of nutrients in oak browse by goats. Journal of Animal Science. 53: 283-290; 1981.

Neilson, R. P. Biogeography of *Quercus gambelii* and *Quercus turbinella* in relation to atmospheric flow structure. Salt Lake City, UT: University of Utah; 1981. 70 p. Ph.D. dissertation.

Neilson, R. P.; Wullstein, L. H. Seedling mortality in Gambel oak. Abstract of paper presented at Pacific Division, AAAS, annual meeting. Moscow, ID, 1979 June 3-7.

Neilson, R. P.; Wullstein, L. H. Moisture gradients and seedling mortality in Gambel oak. Abstract of paper presented at Pacific Division, AAAS, annual meeting. Davis, CA, 1980a June 22-27.

Neilson, R. P.; Wullstein, L. H. Catkin freezing and acorn reproduction in Gambel oak in Utah, 1978. American Journal of Botany. 67: 426-428; 1980b.

Neilson, R. P.; Wullstein, L. H. Biogeography of two southwestern American oaks in relation to seedling drought response and atmospheric flow structure. Biogeography. 10: 275-297; 1983.

Nixon, E. S. An ecological study of an exclosure in the mountain brush vegetation of the Wasatch Mountains, Utah. Provo, UT: Brigham Young University; 1961. 245 p. M.S. thesis.

Nixon, E. S. A comparative study of the mountain brush vegetation in Utah. Great Basin Naturalist. 27: 59-66; 1967.

Nixon, E. S.; Christensen, E. M. An ecological study of an exclosure in the mountain brush vegetation of the Wasatch Mountains, Utah. Proceedings of Utah Academy of Science, Arts, and Letters. 36: 182-183; 1959.

Parker, K. G. Some important Utah range plants. Extension Service Bulletin EC-383. Logan, UT: Utah State University; 1975. 174 p.

Patton, D. R. Deer and elk use of a ponderosa pine forest in Arizona before and after timber harvest. Research Note RM-139. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station; 1969. 7 p.

Pearl, R. W. Gambel oak control in New Mexico. Western Weed Control Conference Progress Report; 1965: 39-40.

Pederson, J. C. The band-tailed pigeon in Utah. Publication 75-1. Salt Lake City, UT: Utah State Department of Natural Resources and Division of Wildlife Resources; 1975. 75 p.

Pendleton, R. C. Some uses of radioactive isotopes in ecological research. Salt Lake City, UT: University of Utah; 1952. 162 p. Ph.D. dissertation.

Perry, W. M. Oakbrush management plan and environmental assessment report for Pleasant Grove Ranger District, Uinta National Forest; 1980. 8 p. Mimeographed.

Perry, W. M. Bill Perry works on oakbrush. In: Utah Section News, Society for Range Management, Issue 81-2; 1981: 3.

Petersen, D. L. Reinventory of surface soil and plant characteristics - Morris Watershed. Salt Lake City, UT: University of Utah; 1954. 48 p. M.S. thesis.

Plumb, T. R. Brushkiller to control scrub oak sprouts. Research Note PSW-146. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station; 1967. 6 p.

Plummer, A. P.; Christensen, D. R.; Monsen, S. B. Highlights, results, and accomplishments of game range restoration studies. Publication 67-4. Salt Lake City, UT: Utah Division of Fish and Game; 1966: 7-9.

Plummer, A. P.; Christensen, D. R.; Monsen, S. B. Restoring big game range in Utah. Publication 68-3. Salt Lake City, UT: Utah Division of Fish and Game; 1968: 56-60.

Plummer, A. P.; Christensen, D. R.; Stevens, R.; Jorgensen, K. R. Highlights, results, and accomplishments of game range restoration studies. Publication 70-3. Salt Lake City, UT: Utah Division of Fish and Game; 1970: 26-30.

Price, R. Artificial reseeding on oak-brush ranges in central Utah. Circular 458. Washington, DC: U.S. Department of Agriculture; 1938. 19 p.

Price, R.; Evans, R. B. Climate of the west front of the Wasatch Plateau in central Utah. Monthly Weather Review. 65: 291-301; 1937.

Rasmussen, D. I. Biotic communites of the Kaibab Plateau, Arizona. Ecological Monographs. 11: 229-275; 1941.

Ream, R. R. An ordination of the oak communities of the Wasatch Mountains. Salt Lake City, UT: University of Utah; 1960. 52 p. M.S. thesis.

Ream, R. R. The vegetation of the Wasatch Mountains, Utah and Idaho. Madison, WI: University of Wisconsin; 1963. 178 p. Ph.D. dissertation.

Remington, C. L. Food plants of *Hypaurotis chrysalus* in Colorado. Journal of Lepidopterist's Society of Japan. 13: 164; 1960.

Reynolds, H. G.; Clary, W. P.; Ffolliott, P. F. Gambel oak for southwestern wildlife. Journal of Forestry. 68: 545-547; 1970.

Rogers, G. F. Then and now: a photographic history of vegetation change in the central Great Basin desert. Salt Lake City, UT: University of Utah Press; 1982. 152 p.

Russo, J. P. The Kaibab north deer herd - its history, problems and management. Wildlife Bulletin 7. Phoenix, AZ: Arizona Game and Fish Department; 1964. 195 p.

Sackett, S. S. Woody fuel particle size and specific gravity of southwestern tree species. Research Note RM-389. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station; 1980. 4 p.

Sampson, A. W. The foothill-montane-alpine flora and its environment. In: Tidestrom, I. Flora of Utah and Nevada. U.S. National Herbarium Contributions. 25: 24-31; 1925.

Sandberg, D. V.; Pierovitch, J. M.; Fox, D. G.; Fox, E. W. Effects of fire on air: a state-of-knowledge review. General Technical Report WO-9. Washington, DC: U.S. Department of Agriculture, Forest Sevice; 1979. 40 p.

Sargent, C. S. Manual of trees of North America (exclusive of Mexico). Boston, MA: Houghton Mifflin Company; 1926. 910 p.

Saul, W. E. A descriptive catalog of the trees and larger woody shrubs of Utah based on the anatomy of the wood. Salt Lake City, UT: University of Utah; 1955. 273 p. Ph.D. dissertation.

Schier, G. A. Vegetative regeneration of Gambel oak and chokecherry from excised rhizomes. Forest Science. 29: 499-502; 1983.

Schoenfeld, E. Thousands of Utahns cutting their own wood. Salt Lake City, UT: Deseret News, 1979 November 16: B-1, B-10.

Scifres, C. F.; Stuth, J. W.; Bovey, R. W. Control of oaks (*Quercus* spp.) and associated woody species on rangelands with tebuthiuron. Weed Science. 29: 270-275; 1981.

Shepherd, H. R. Effects of clipping on key browse species in southwestern Colorado. Technical Publication 28. Fort Collins, CO: Colorado Division of Game, Fish, and Parks; 1971: 32-42, 86, 90-91, 99.

Singh, A. P.; Mogensen, H. L. Fine structure of the zygote and embryo in *Quercus gambelii*. American Journal of Botany. 62: 105-115; 1975.

Smith, A. D. Feeding deer on browse species during winter. Journal of Range Management. 3: 130-132; 1950.

Smith, A. D. Consumption of native forage species by captive mule deer during summer. Journal of Range Management. 6: 30-37; 1953.

Smith, A. D. Nutritive value of some browse plants in winter. Journal of Range Management. 10: 162-164; 1957.

Smith, A. D.; Hubbard, R. L. Preference ratings for winter deer forage from northern Utah ranges based on browsing time and forage consumed. Journal of Range Management. 8: 262-265; 1954.
Smith, J. G. Deer forage observations in Utah. Journal of Wildlife Management. 13: 314-315; 1949.
Smith, J. G. Food habits of mule deer in Utah. Journal of Wildlife Management. 16: 148-155; 1952.
Smith, R. J. Court reluctantly upholds EPA on 2,4,5-T suspension. Science. 204: 602; 1979.
Steinhoff, H. W. Management of Gambel oak associations for wildlife and livestock. Denver, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Region and Colorado State University; 1978. 119 p. Unpublished report.
Steinhoff, H. W. Gambel oak ecology. Durango, CO: Colorado State University, district office report; 1981. 5 p. Limited distribution.
Stoddart, L. A.; Holmgren, A. H.; Cook, C. W. Important poisonous plants of Utah. Special Report 2. Logan, UT: Utah State Agricultural College, Agricultural Experiment Station; 1949. 21 p.
Sutton, R.; Johnson, R. C. Landscape plants from Utah's mountains. Bulletin EC-368. Logan, UT: Utah State University Extension Service; 1974. 135 p.
Sweeney, J. R. Effects of snow on oakbrush. Fort Collins, CO: Colorado State University; 1975. 101 p. Ph.D. dissertation.
Sweeney, J. R.; Steinhoff, H. W. Effects of snow on oakbrush. In: Steinhoff, H. W.; Ives, J. D., eds. Ecological impacts of snowpack augmentation in the San Juan Mountains of Colorado. Denver, CO: U.S. Department of the Interior, Bureau of Reclamation, final report; 1976: 343-366.
Tew, R. K. Soil moisture depletion by Gambel oak in northern Utah. Research Note INT-54. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1966. 7 p.
Tew, R. K. Soil moisture depletion by Gambel oak in central Utah. Research Note INT-74. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1967. 8 p.
Tew, R. K. Converting Gambel oak sites to grass reduces soil-moisture depletion. Research Note INT-104. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1969. 4 p.
Thomas, J. W. A comparison of vegetation changes in a mountain brush type after grazing and protection from grazing during thirty-seven years. Provo, UT: Brigham Young University; 1970. 37 p. M.S. thesis.
Tidestrom, I. Flora of Utah and Nevada. Contribution of United States Herbarium, vol. 25. Washington, DC: Government Printing Office; 1925. 665 p. plus 15 plates.
Toland, J. R. The potential of utilizing chaparral for energy. In: Conrad, C. E.; Oechel, W. C., technical coordinators. Dynamics and management of Mediterranean-type ecosystems. General Technical Report PSW-58. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station; 1982: 186-192.
Tucker, J. M. Studies in the *Quercus undulata* complex. I. A preliminary statement. American Journal of Botany. 48: 202-208; 1961.
Tucker, J. M. Studies in the *Quercus undulata* complex. III. The contribution of *Q. arizonica*. American Journal of Botany. 50: 699-708; 1963.
Tucker, J. M. Studies in the *Quercus undulata* complex. IV. The contribution of *Q. havardii*. American Journal of Botany. 57: 71-84; 1970.
Tucker, J. M.; Cottam, W. P.; Drobnick, R. Studies in the *Quercus undulata* complex. II. The contribution of *Q. turbinella*. American Journal of Botany. 48: 329-339; 1961.
Tucker, J. M.; Neilson, R. P.; Wullstein, L. H. Hermaphroditic flowering in Gambel oak. American Journal of Botany. 67: 1165-1267; 1980.
Urquhart, T. P. An ecological study of deer mice, *Peromyscus maniculatus* (Wagner), and chipmunks, *Eutamias umbrinus* (Allen) in an ecotone in Utah. Salt Lake City, UT: University of Utah; 1968. 50 p. M.S. thesis.
U.S. Department of Agriculture, Agricultural Research Service. Twenty-two plants poisonous to livestock in the western States. ARS Agriculture Information Bulletin 327. Washington, DC: U.S. Department of Agriculture; 1968. 64 p.
U.S. Department of Agriculture, Forest Service. Range plant handbook. Springfield, VA: U.S. Department of Commerce, National Technical Information Service; 1937. 537 p.
U.S. Department of Agriculture, Forest Service. Conversion of the thicket covered areas to productive grazing lands. Range Improvement Notes. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Region; 1966; 11: 1-4.
U.S. Department of Agriculture, Forest Service. Seeds of woody plants in the United States. Agriculture Handbook 450. Washington, DC; 1974. 883 p.
U.S. Department of Agriculture, Forest Service. Gambel oak. Wildlife Management Staff Report. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Region; 1983. 5 p.
Vallentine, J. F. Range development and improvements. Provo, UT: Brigham Young University Press; 1971. 516 p.
Vallentine, J. F.; Schwendiman, D. Spot treatment for Gambel oak control. Journal of Range Management. 26: 382-383; 1973.
Van Epps, G. A. Control of Gambel oak with three herbicides. Journal of Range Management. 27: 297-301; 1974.
Vander Wall, S. B.; Balda, R. P. Coadaptations of the Clark's nutcracker and the pinyon pine for efficient seed harvest and dispersal. Ecological Monographs. 47 89-111; 1977.
Wagstaff, F. J. Economic considerations in use and management of Gambel oak for fuelwood. General Technical Report INT-165. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1984. 8 p.

Welch, B. L.; Monsen, S. B.; Shaw, N. L. Nutritive value of antelope and desert bitterbrush, Stansbury cliffrose, and apache-plume. In: Tiedemann, A. R.; Johnson, K. L., compilers. Proceedings - research and management of bitterbrush and cliffrose in western North America. General Technical Report INT-152. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1983: 173-185.

Wells, P. V. Physiognomic intergradiation of vegetation on the Pine Valley Mountains in southwestern Utah. Ecology. 41: 553-556; 1960.

Wells, P. V. Paleobiogeography of montane islands in the Great Basin since the last glaciopluvial. Ecological Monographs. 53: 341-382; 1983.

Welsh, S. L.; Moore, G. Utah plants: Tracheophyta. Provo, UT: Brigham Young University Press; 1973. 474 p.

Woodbury, A. M.; Durrant, S. D.; Flowers, S. Survey of vegetation in the Navajo Reservoir basin. Anthropology Paper 51. Salt Lake City, UT: University of Utah; 1961. 99 p.

Woodbury, A. M.; Durrant, S. D.; Flowers, S. A survey of vegetation in the Curecanti Reservoir basins. Anthropology Paper 56. Salt Lake City, UT: University of Utah; 1962. 98 p.

Yake, S.; Brotherson, J. D. Differentiation of serviceberry habitats in the Wasatch Mountains of Utah. Journal of Range Management. 32: 379-383; 1979.

Young, J. A.; Evans, R. A. Something of value - energy from wood on rangelands. Rangelands. 3: 10-12; 1981.

GOVERNMENT PRINTING OFFICE: 1985-0-576-040/10528

Harper, Kimball T.; Wagstaff, Fred J.; Kunzler, Lynn M. Biology and management of the Gambel oak vegetative type: a literature review. General Technical Report INT-179. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1985. 31 p.

A total of 231 articles dealing with Gambel oak (*Quercus gambelii* Nutt.) covering the period 1890 through 1983 are reviewed. The basic biology of the species, its distribution, and ecological relationships are discussed. Management of the species for various purposes is described.

KEYWORDS: Gambel oak, management, biology, literature review

PESTICIDE PRECAUTIONARY STATEMENT

This publication reports research involving pesticides. It does not contain recommendations for their use, nor does it imply that the uses discussed here have been registered. All uses of pesticides must be registered by appropriate State and/or Federal agencies before they can be recommended.

CAUTION: Pesticides can be injurious to humans, domestic animals, desirable plants, and fish or other wildlife—if they are not handled or applied properly. Use all pesticides selectively and carefully. Follow recommended practices for the disposal of surplus pesticides and pesticide containers.

PROTECT

Use Pesticides Safely

FOLLOW THE LABEL

U.S. DEPARTMENT OF AGRICULTURE

The Intermountain Station, headquartered in Ogden, Utah, is one of eight regional experiment stations charged with providing scientific knowledge to help resource managers meet human needs and protect forest and range ecosystems.

The Intermountain Station includes the States of Montana, Idaho, Utah, Nevada, and western Wyoming. About 231 million acres, or 85 percent, of the land area in the Station territory are classified as forest and rangeland. These lands include grasslands, deserts, shrublands, alpine areas, and well-stocked forests. They supply fiber for forest industries; minerals for energy and industrial development; and water for domestic and industrial consumption. They also provide recreation opportunities for millions of visitors each year.

Field programs and research work units of the Station are maintained in:

Boise, Idaho

Bozeman, Montana (in cooperation with Montana State University)

Logan, Utah (in cooperation with Utah State University)

Missoula, Montana (in cooperation with the University of Montana)

Moscow, Idaho (in cooperation with the University of Idaho)

Provo, Utah (in cooperation with Brigham Young University)

Reno, Nevada (in cooperation with the University of Nevada)